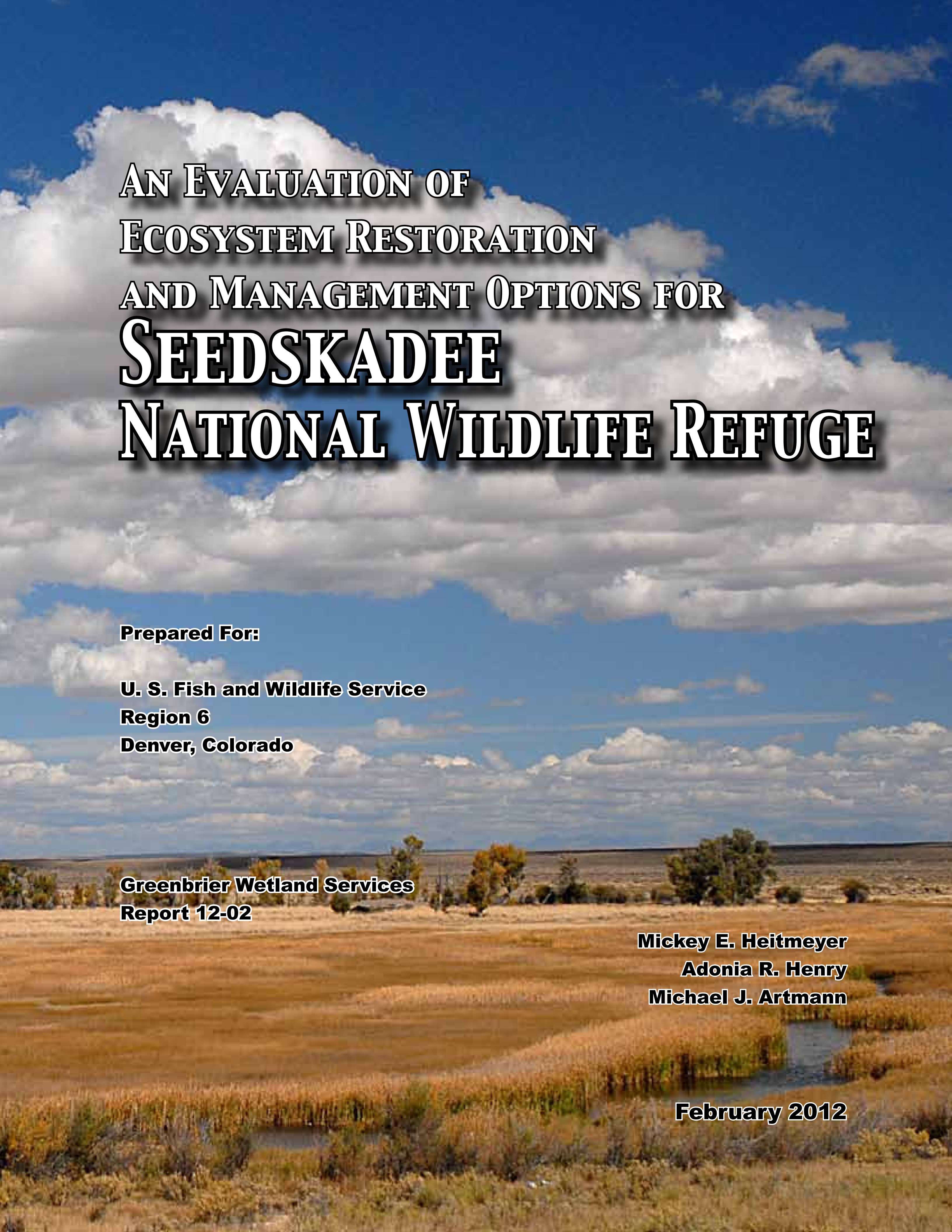

An Evaluation of Ecosystem Restoration and Management Options for Seedskadee National Wildlife Refuge

Prepared For:

U. S. Fish and Wildlife Service
Region 6
Denver, Colorado

Greenbrier Wetland Services
Report 12-02

Mickey E. Heitmeyer
Adonia R. Henry
Michael J. Artmann

February 2012

HYDROGEOMORPHIC EVALUATION
OF
ECOSYSTEM RESTORATION
AND MANAGEMENT OPTIONS FOR
SEEDSKADEE NATIONAL WILDLIFE REFUGE

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Adonia Henry

Karen Kyle

EXECUTIVE SUMMARY

This study provides an evaluation of ecosystem restoration and management options for Seedskadee National Wildlife Refuge (NWR) in southwestern Wyoming using Hydrogeomorphic Methodology (HGM). The HGM evaluation obtained and analyzed historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) plant and animal communities, and 6) physical anthropogenic features of the Seedskadee ecosystem.

Seedskadee NWR contains about 27,230 acres along 36 miles of the Green River downstream from Fontenelle Reservoir. The current surficial geology of the refuge reflects the complex geological history of the region and contains the active Holocene-derived Green River channel and floodplain, the structural terrace of the Bridger Formation, relict alluvium of tributary channels, and alluvial fans eroded from surrounding uplands. Contemporary soil data and maps are not available for the refuge, but gross-scale soil maps prepared for the refuge in 1957 indicate a heterogeneous distribution of soil types with moderately deep sandy loam alkaline soils in the Green River floodplain, deep clay alkali soils on alluvial fans, intermingled gravel and shallow loam soils on recent terraces, and clay saline and shallow gravelly soils on upland terraces and benches. Recent LIDAR topographic surveys were conducted on the refuge during 2010 and provide detailed elevation information for the area.

The climate of southwestern Wyoming is desert steppe with low average annual precipitation (6.48 inches) and a short 103-day growing season. Evapotranspiration is about 3-5 times annual precipitation. The Green River and its major tributaries, especially the Big Sandy River, historically were the primary sources of surface water at Seedskadee NWR. River and stream flow characteristics are influenced by annually dynamic snowpack in the watershed. Mean annual Green River flows upstream of Seedskadee NWR prior to Fontenelle Reservoir identify dynamic annual peak flows, mainly in June, and that Green River flows capable of causing substantial flooding of floodplains on Seedskadee NWR were common. Historically, a Green River discharge of > 10,000 cfs upstream from Seedskadee NWR occurred in about half of all years. Discharges of at least 15,000 cfs occurred about once every 4-5 years and flood events of > 20,000 cfs occurred in 3 of 36 years at Green River, Wyoming from 1898 to 1922.

Various data and analyses indicate that a Green River discharge of about 8,000 to 10,000 cfs causes water from the river to enter low elevation floodplain swales on Seedskadee NWR. Aerial photographs during a 16,800 cfs event on the Green River in September 1965 indicated widespread flooding on the refuge prior to when most levees and water-control structures on the refuge were present. Models of potential flooding distribution on Seedskadee NWR were prepared using visual estimates of the distribution of historical flooding and hydraulic analysis with HEC-RAS. Visual models used LIDAR topographic data, stage-discharge relationships up to 14,000 cfs, and the 1965 aerial photographs. HEC-RAS models used steady-state water surface profile computations, energy-loss equations, and LIDAR. The modeled distribution of flood inundation was similar between the visual and HEC-RAS methods in areas where water-control infrastructure developments were limited, but varied to some degree where extensive dike construction has occurred and in areas that were flooded when LIDAR was flown. Despite some data limitations, both models identified patterns of historical and contemporary flood frequency based on location in the floodplain, past river migration routes, and river stage. Typically, floodwaters tend to enter floodplain bottoms in the Upper Green River from the downstream end of point bars, floods old river channels and floodplain swales first, and then floodwaters gradually inundate higher floodplain ridges, swales, and terraces. At discharges > 14,000 cfs, water from the Green River begins to overtop upstream river bend areas and natural levees and connects upstream flood headwaters with downstream backwaters.

Seedskadee NWR contains relatively narrow floodplains along the Green and Big Sandy Rivers embedded within a sagebrush-dominated upland steppe landscape. Areas adjacent to the Green River channel historically contained linear bands of riparian woodland, especially on the insides of river bend point bars. Floodplain meander scrolls, high flow channels, and depressions historically contained wetlands ranging from small areas of persistent emergent vegetation communities in deeper more frequently flooded sites to seasonally flooded sedge-rush communities in shallow sites. Upland areas at Seedskadee NWR historically were dominated by sagebrush-steppe communities. A hydrogeomorphic matrix of relationships of vegetation communities to geomorphic surface, soils, topography, and hydrology was developed to map the potential distribution of Presettlement communities at Seedskadee NWR. Generally, historical (and current) vegetation communities at Seedskadee NWR were arrayed as "bands" or "zones" from the Green River channel to the uplands on the edges of the floodplain and their distribution was strongly defined by the combination of elevation and hydrology. Most wetland habitats historically on the refuge were seasonally flooded types. Diverse animal communities historically were present in the various habitats at Seedskadee NWR. The historic nature of wetlands on the refuge, provided mainly spring and early summer flooding that was most beneficial to spring migrant waterbirds. More extensive summer flooding and breeding habitat was limited to small deep floodplain depressions, such as abandoned river channels, and in wet years.

This study obtained contemporary information on: 1) physical features, 2) land use and management, 3) hydrology, 4) vegetation communities, and 5) fish and wildlife populations on Seedskadee NWR where available. These data chronicle the history of land and ecosystem changes at and near the refuge from the Presettlement period and provide perspective on when, how, and why alterations have occurred to ecological communities and processes on the refuge. The major changes in the Seedskadee NWR ecosystem since the late-1800s have been: 1) alterations to the distribution, chronology, and abundance of surface and groundwater, especially following construction and subsequent operation of Fontenelle Reservoir; 2) alteration of native sagebrush-steppe and grassland communities from intensive livestock grazing; 3) reduced and altered riparian woodland; and 4) altered topography including many levees, roads, ditches, borrow areas, and water-control structures.

Since establishment of the refuge in 1965, many wetland developments have occurred; the most substantial water-control infrastructure was built or rehabilitated in the 1980s in the Hamp, Hawley, Lower Hawley, Cottonwood, Pal, and Dunkle impoundments. Management of these impoundments typically has sought to flood pools in mid-March and then to maintain full pool levels through summer and fall to provide breeding and fall migration habitat for waterbirds, especially dabbling ducks and trumpeter swans. A consequence of the annual semipermanent to permanent flooding of impoundments has been an increase in coverage of persistent emergent vegetation, primarily cattail, and decreased wetland and waterbird productivity.

Invasive plant species have expanded greatly in many floodplain and some upland areas on Seedskadee NWR. Biological, mechanical, and chemical control methods have been used to manage these invasive plants. Older cottonwood stands in riparian areas are deteriorating rapidly and little new recruitment is occurring. Several attempts have been made to restock cottonwood in select riparian sites using direct planting and fencing of saplings, but with minimal success.

The future condition of the Seedskadee NWR ecosystem is, and will continue to be, highly affected by the presence and operation of Fontenelle Reservoir and Dam. The impetus for establishing Seedskadee NWR was to mitigate fish and wildlife habitat losses from the reservoir (and other older proposed diversions of water from the Green River). Consequently, future management of Seedskadee must attempt to sustain and restore historical communities and resources in this region of the Green River Valley and to manage all habitats (sagebrush-steppe, floodplain wetlands, riparian woodland, riverine) to provide historical resources used and required by native animal species within the constraints imposed by the management of water storage and releases from Fontenelle Reservoir. Given this management context, and based on the HGM context of information obtained and analyzed in this study, future management of Seedskadee NWR should seek to meet the following goals:

1. Maintain and restore the physical and hydrological character of the Green River (below Fontenelle Reservoir) and the Big Sandy River as best possible.
2. Restore the natural topography, water regimes, and surface water flow and flooding patterns from the Green River into and across the Green River floodplain and sheetwater runoff into and across adjacent terraces and alluvial fans.
3. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

Specific recommendations to meet the above goals include actions to:

Subgoal 1.1. *Protect the physical integrity of the Green and Big Sandy Rivers and their upstream watersheds.*

Subgoal 1.2. *Cooperate with the U.S. Bureau of Reclamation to manage water releases from Fontenelle Reservoir in a more natural seasonal and inter-annual flow regime.*

Subgoal 2.1. *Restore natural topography and reconnect natural water flow patterns and pathways where possible.*

Subgoal 2.2. *Manage wetland impoundments and natural floodplain depressions for more natural seasonal and long-term water regimes based on their hydrogeomorphic attribute position.*

Subgoal 3.1. *Protect and restore native vegetation composition to upland sagebrush-steppe areas.*

Subgoal 3.2. *Restore linear bands of riparian woodland along the Green and Big Sandy Rivers.*

Subgoal. 3.3. *Restore complexes of floodplain wetland communities with natural water regimes.*

Individual actions to address each of the above subgoals are described in the report.

Future management of Seedskadee NWR should include regular monitoring and directed studies to determine how ecosystem structure and function are changing, regardless of whether restoration and management options identified in this report are undertaken. Ultimately, the success in restoring and sustaining communities and ecosystem functions/values at Seedskadee NWR will depend on how well the physical and hydrological integrity of the Green River Valley is protected and how key ecological processes and events, especially pulsed late-spring and early-summer flooding, can be restored or emulated by management actions. Uncertainty exists about the ability to make some system changes because of constraints of Fontenelle Reservoir management, water rights and historical uses, and land uses in the larger Green River watershed, including the Big Sandy River drainage. Also, techniques for controlling or reducing introduced plant species and restoring cottonwood are not entirely known. Especially critical information and monitoring needs for Seedskadee NWR include:

1. Key baseline ecosystem data on soils, vegetation inventory and mapping, animal species occurrence and abundance, and water levels.

2. Effects of attempts to restore natural water regimes and flow patterns including refinement of inundation mapping models.

3. Long-term changes in vegetation and animal communities.

Karen Kyle

INTRODUCTION

Seedskadee National Wildlife Refuge (NWR) contains about 25,970 acres of riverine, riparian woodland, floodplain wetland, and upland sagebrush steppe habitats along 36 miles of the Green River in Sweetwater County in southwestern Wyoming (Fig. 1). The refuge was authorized in 1956 through the Colorado River Storage Project Act (USFWS 2002). This Act provided for the development of wildlife habitat to offset the loss of habitat that resulted when Flaming Gorge Dam was built below, and Fontenelle Dam was built above the refuge on the Green River. Fontenelle Dam was built on the Green River from 1961-64 and in 1965 Seedskadee NWR was established through a Memorandum of Understanding between the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service (USFWS). The name Seedskadee originated from the Shoshone Indian word “Sisk-a-dee-agie” meaning “river of the prairie hen.”

The area of southwestern Wyoming in and near Seedskadee NWR is rich in cultural history and resources because the area was used extensively by nomadic Indian tribes, fur trappers and traders, and early pioneers. Hundreds of thousands of pioneers crossed the Green River on the current Seedskadee NWR using the Oregon and Mormon Trails (Haines 1996). Jim Bridger, a trapper and frontiersman, and others operated ferries on the Green River in the 1840s and 1850s. The Green River and its floodplain essentially was an “oasis” of water and lush vegetation that bisected the vast high desert sagebrush plains of southwest Wyoming and was a welcome respite

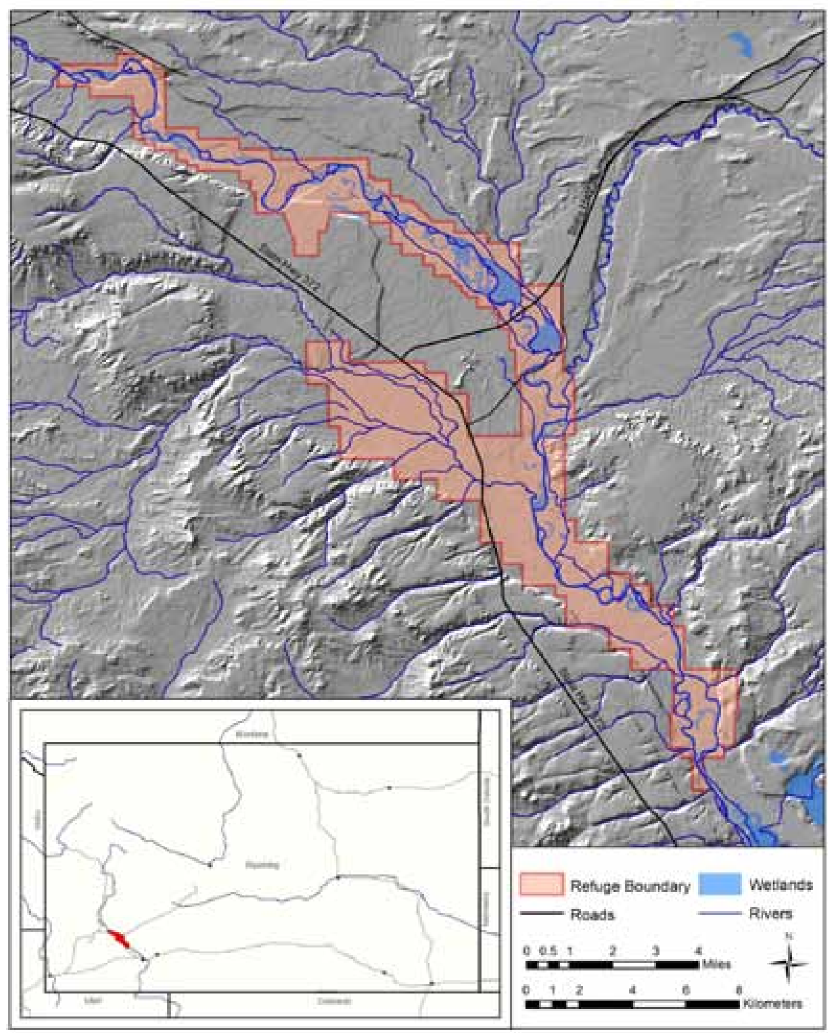


Figure 1. General location of Seedskadee National Wildlife Refuge on the Green River, Wyoming.

for travelers and settlers. Ecological resources in the Green River and its floodplain and adjacent sagebrush steppe habitats supported a diverse assemblage of plant communities and abundant populations of many fish and wildlife species (Dorn 1986).

Seedskadee NWR is an important part of the Upper Green River ecosystem, contains priority communities for the Wyoming Landscape Conservation Initiative (WLCI 2008), and is a critical public land ownership part of the Great Northern Landscape Conservation Cooperative (USFWS 2010). In 2002, the USFWS completed a Comprehensive Conservation Plan (CCP) for Seedskadee NWR. The CCP process sought to articulate the management direction for the refuge for 15 years and it developed goals, objectives, and strategies to define the role of the refuge and its contribution to the regional landscape in which it sets, and the overall mission of the NWR system. Design and implementation of the previously completed CCP for Seedskadee NWR now is being facilitated by an evaluation of ecosystem restoration and management options using Hydrogeomorphic Methodology (HGM) (Heitmeyer 2007). HGM analyzes historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrologic condition and flood frequency, 5) aerial photographs and cartography maps, 6) land cover and vegetation communities, 7) key plant and animal species, and 8) physical anthropogenic features of the Seedskadee ecosystem. HGM now is commonly used to evaluate ecosystems on NWR's (e.g., Heitmeyer and Fredrickson 2005, Heitmeyer and Westphall 2007, Heitmeyer et al. 2009, Heitmeyer et al. 2010a,b) and provides a context to understand the physical and biological formation, features, and ecological processes of lands within the NWR and surrounding region. This historical assessment then provides the foundation, or baseline condition, to determine what changes have occurred in the abiotic and biotic attributes of the ecosystem and how these changes have affected ecosystem structure and function. Ultimately, HGM helps define the capability of the area to provide key ecosystem functions and values and identifies options that can help to restore and sustain fundamental ecological processes and resources.

This report provides HGM analyses for Seedskadee NWR with the following objectives:

1. Identify the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Green River Valley near Seedskadee NWR.

2. Evaluate changes in the Seedskadee NWR ecosystem from the Presettlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.

3. Identify restoration and management options and ecological attributes needed to successfully restore specific habitats and conditions within the Seedskadee NWR region.

Cary Aloia

THE HISTORIC SEEDSKADEE ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

Seedskadee NWR is within the Green River Structural Basin, one of the largest Rocky Mountain Intermountain basins (Mason and Miller 2005). Physical boundaries of the basin are the Gros Ventre and Wind River Ranges to the north, the Rock Springs uplift to the east, the east-west trending Uinta Mountains to the south, and the east thrust front of the Wyoming Range-Overthrust Belt to the west (Dover and M'Gonigle 1993). Precambrian rocks underlie the Green River Structural Basin at about 26,000 feet below the surface; the intervening sedimentary rock consequently is variably thick between surface and Precambrian rock (Blackstone 1993). Bedrock geology of Seedskadee NWR is comprised of alluvium and colluviums within the Green River floodplain and Bridger Formation sedimentary rock under upland terraces (Fig. 2). A small amount of the upper and lower parts of the refuge are underlain by Green River Formation rocks. The Precambrian history of Wyoming is poorly understood, but was one of seven Achaean provinces that form the North American craton. During the Middle Proterozoic Era, Wyoming had widespread magmatisim (Snoke 1993); no Precambrian rocks are exposed in Sweetwater County. The Precambrian basement rocks had low relief during the early to middle Paleozoic Era, which created only a thin accumulation of sedimentary rocks. The Green River Structural Basin probably had depositional and structural conditions in the Paleozoic Era that were relatively stable and constant (Krueger 1960). In the Late Paleozoic Era, sediments in the region were deposited by shallow seas and changes in sea level or tectonic activity periodically left some areas above

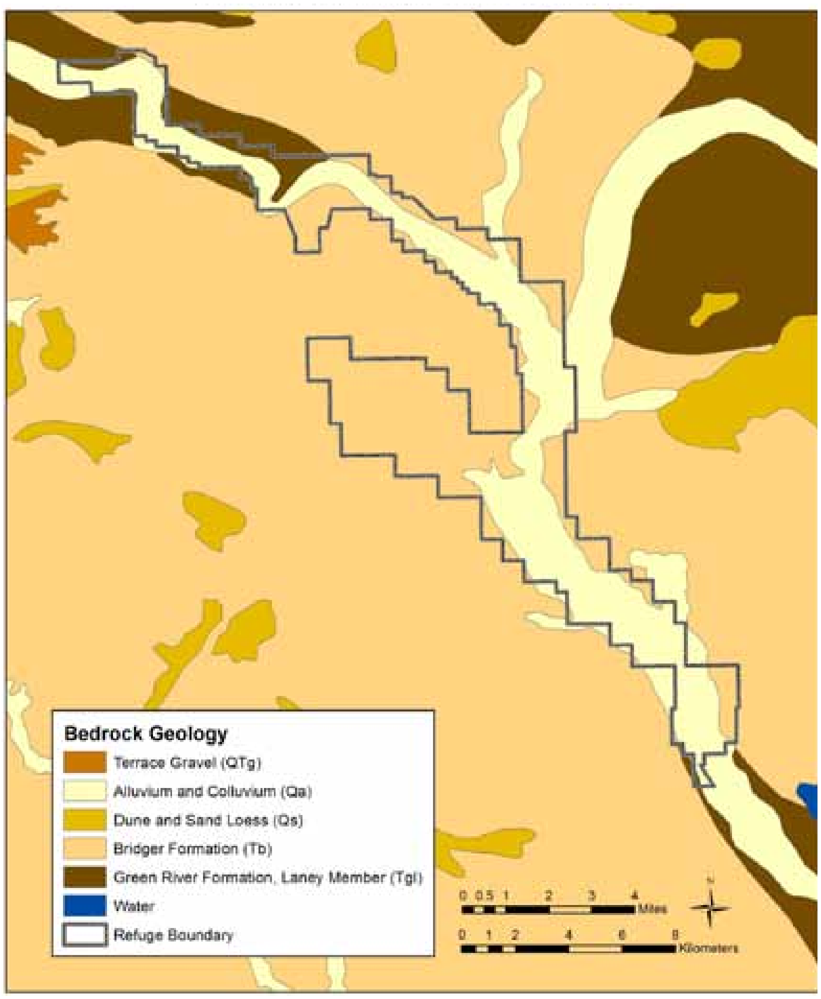


Figure 2. Bedrock geology at Seedskadee National Wildlife Refuge (from Love and Christianson 1985).

sea level, which caused erosion and unconformities in land surfaces.

In the Mesozoic Era, southwestern Wyoming was marked by marine sediments and relatively stable conditions until the Late Cretaceous Period (Krueger 1960). In the Triassic Period, land emergence again caused erosion and unconformity and periodic emergence of land during the Jurassic Period caused deposition of non-marine Nugget Sandstone and Morrison Formation. The Cretaceous Period in Wyoming was dominated by an epicontinental sea and erosion of sediments west of the sea resulted in thick accumulation of sediments in the marine basin. The Late Cretaceous Period was marked by tectonic activity and the Sevier orogeny created a fold and thrust belt west of the present day Sweetwater County, while the Laramide orogeny deformed most of the rest of Wyoming. The ancestral Green River was formed by the Laramide Orogeny (Krueger 1960, Welder and McGreevy 1966). The most notable geological development in the Seedskadee region in the Tertiary Period was the formation of Lake Gosiute during the middle Eocene Epoch. At its maximum extent, this lake covered all of Sweetwater County and sediments deposited in the lake are known as the Green River Formation (Bradley 1964). This formation is a fine-grained calcareous sedimentary rock embedded in thick sandy mudstone that filled the large inter-montane basin. The mudstone that composes the Green River Formation is divided into the Watasch and Bridger Formations above and below the Green River Formation, respectively. Lake Gosiute subsided throughout much of the Eocene Epoch and allowed for deposition of the thick fluvial sediments encompassing the lake deposits; these contain quantities of subbitumious low sulfur coal, oil, natural gas, and soda ash (trona) (Lowham et al. 1985, Roehler 1993).

The formation of Lake Gosiute may have been caused by a reversal of drainage when the east flowing streams of the Paleocene and early Eocene Epochs changed direction in response to the westward tilting of the Wyoming foreland (Love et al. 1963). Filling of the lake basin with sediment led to the extinction of the lake in the middle Eocene (Hansen 1986). Few Tertiary rocks from the Lake Gosiute period occur in Sweetwater County. After Lake Gosiute disappeared, fluvial sediments and tephra were deposited in the region; regional uplifts occurred in two pulses between the late Oligocene and late Pleistocene Epochs (Flanagan and Montagne 1993). In the late Miocene, large river systems including the Green River began to develop and erode older sediments from the basin. This fluvial development initiated the degradation regime in Wyoming that continues to today and was the beginning of the modern drainage system of the region.

During the Quaternary Period, headward erosion of the Green River drainage continued to remove sediments from the old Lake Gosiute basin and other uplift areas and moved the sediments, through fluvial transport, to the Gulf of California (Veatch 1907). This headward erosion continues to today, except that sediments currently are captured in Fontenelle Reservoir and other downstream reservoirs. Quaternary sand dunes are found in most areas of Sweetwater County including the Seedskadee NWR area (Love and Christiansen 1985). Some of these dune fields have been intermittently active for the last 20,000 years and record climatic fluctuations associated with the stades and interstades of continental glaciations (Gibbons et al. 1990). A few Pleistocene playa lakes and other lacustrine deposits occur in the north-central part of the Green River Structural Basin.

The current surficial geology of the refuge contains the active Holocene Green River channel and floodplain, the structural terrace of the Bridger Formation, relict alluvium of tributary channels, and alluvial fans (Fig. 3). The Green River floodplain at Seedskadee NWR is about one to one and half miles wide. This surficial geomorphology, dominated by the Holocene Green River floodplain, reflects Quaternary movement and sinuous migration of the Green River and the erosion of upland terraces adjacent to the floodplain.

SOILS

Contemporary USDA soil maps for Seedskadee NWR (and most of southwest Wyoming) are not available. Gross-scale maps prepared for the refuge in 1957 (Soil Conservation Service 1957) indicate a heterogeneous distribution of soil types with moderately deep sandy and loam soils that are strongly alkaline near the Green River in floodplains and on natural levees; deep clayey, alkali soils on alluvial fans; intermingled gravel and shallow loam soils on recent terraces; moderately deep clay saline-alkali and shallow gravelly soils on upland terraces; and moderately deep sandy soils on remnant terraces and upland benches (Fig. 4).

TOPOGRAPHY

LIDAR elevation surveys were conducted for the refuge region during summer 2010 (Fig. 5). Generally elevations range from 6,182 to 6,398 feet above mean sea level (amsl) and slope from north to south in the Green River floodplain corridor. Elevations commonly rise 200-300 feet from floodplain bottoms to adjacent terraces and uplands. The Little Dry Creek Valley slopes into the Green River floodplain on the west side of the refuge and the Big Sandy River floodplain merges with the Green River on the east side. The floodplain topography contains numerous relict scour and deposition surfaces created by historic fluvial dynamics of the Green River including abandoned channels, oxbows, high water floodflow channels, natural levees, point bar deposits, and floodplain depressions (Fig. 6). Elevations within each river bend area of the wetland units range from about 10-20 feet with the exception of Pal, which is almost a 35 foot range (Table 1). Relatively subtle topographic changes of 1-3 feet commonly occur from the bottom of old meander scrolls or "swales" to adjacent depositional floodplain "ridges."

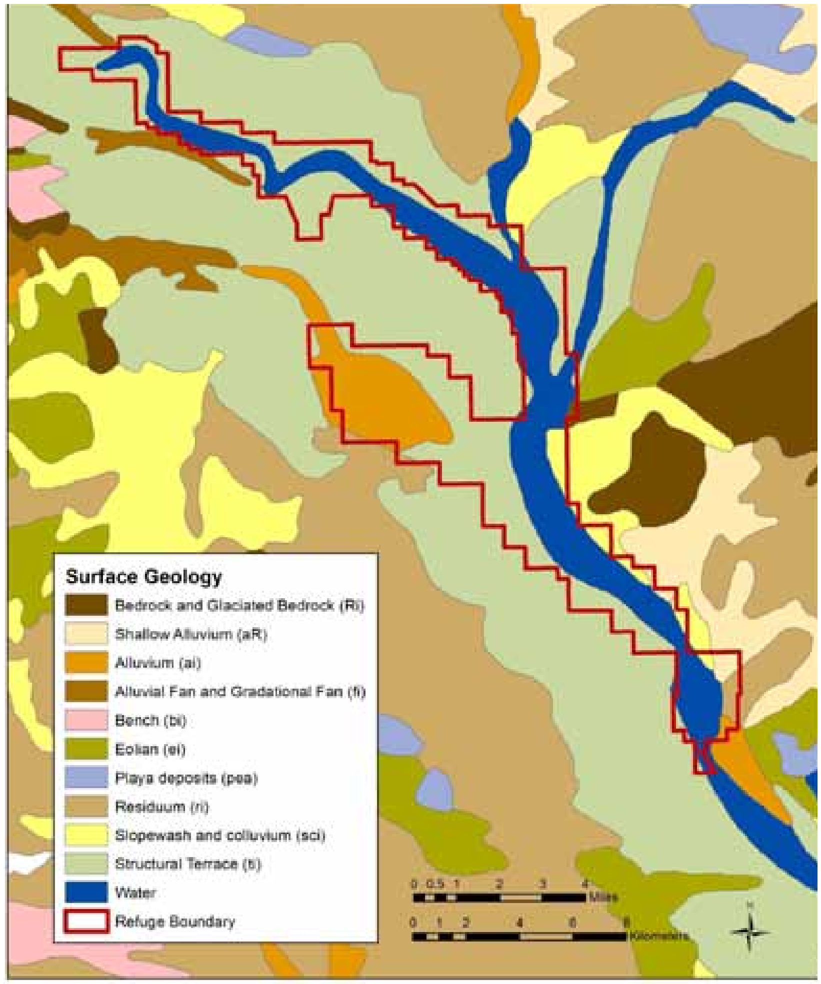


Figure 3. Surficial geomorphic surfaces at Seedskadee National Wildlife Refuge (from Case et al. 1998).

CLIMATE AND HYDROLOGY

The climate of the Seedskadee NWR region of southwestern Wyoming (in Sweetwater County) is broadly classified as desert and steppe (Mason and Miller 2005) The region has warm summers but cold winters and has a short 103-day annual frost-free period (Fig. 7a). Total annual precipitation at Green River, Wyoming averages 6.48 inches but is highly variable among years ranging from 3.82 inches in 1974 to 14.08 inches in 1947 (Fig. 8). Maximum rainfall occurs from May to July with a secondary increase in rainfall in September (Fig. 7b). Large peak pulses of annual precipitation > 11 inches have occurred 11 times since 1913 while extremely dry years with < 5 inches of precipitation have occurred 5 times during that period of record at Green River. Evapotranspiration is high in the Seedskadee NWR region, and often exceeds annual precipitation by 3-5 times.

The Green River and its major tributaries, especially the Big Sandy River, historically were the primary sources of surface water at Seedskadee NWR. Hydrology in the northern part of Seedskadee NWR is influenced mainly by Green River and headwater tributary flows, while the southern part of the refuge also is influenced by flows derived from the confluence of the Green and Big Sandy Rivers. River and stream flow characteristics in the Green River Basin are influenced by the diverse physiography and climate of southwestern Wyoming. The Green River at Seedskadee is a sand-cobble bed system with a meandering sinuosity of 1.56 and an average channel gradient rate-of-fall of 0.9 m/km (Glass 2002). Moderate to large flows in the Green River are the result of runoff from snowmelt, mostly from the Wind River Mountain Range, where the Green River originates.

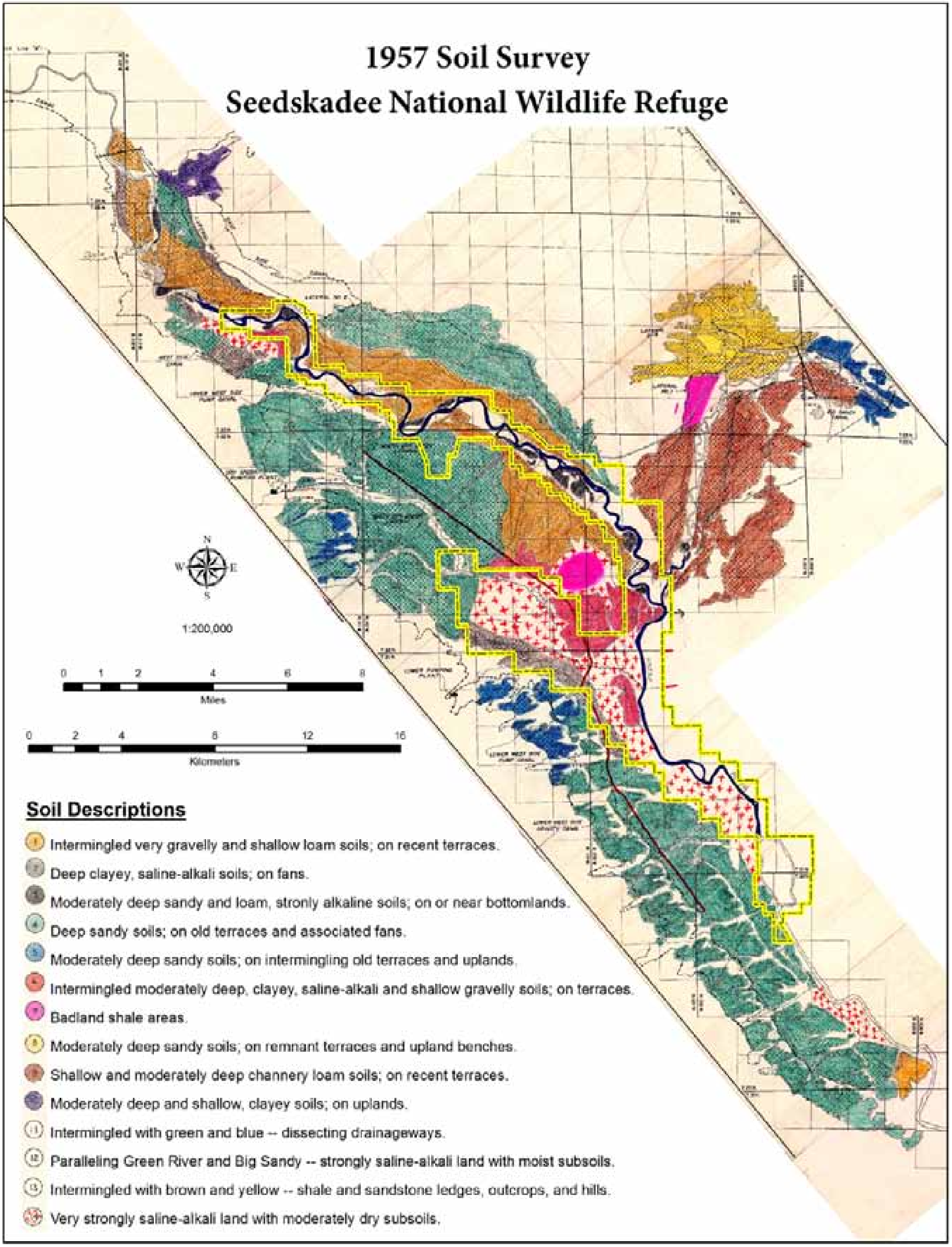


Figure 4. Soil descriptions in the vicinity of Seedskadee National Wildlife Refuge (from Soil Conservation Service 1957).

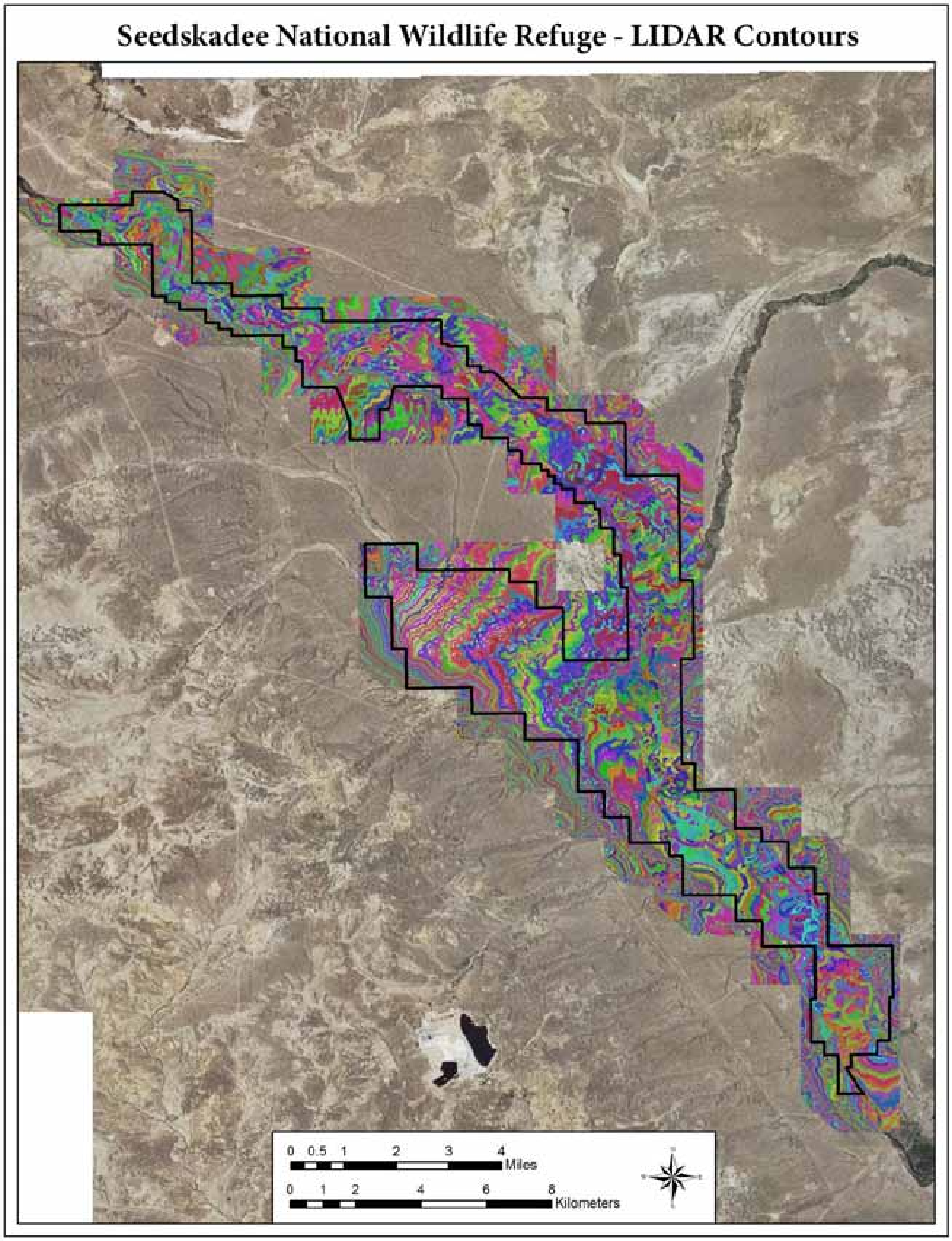


Figure 5. LIDAR topographic contours (one foot) on Seedskadee National Wildlife Refuge, 2010.

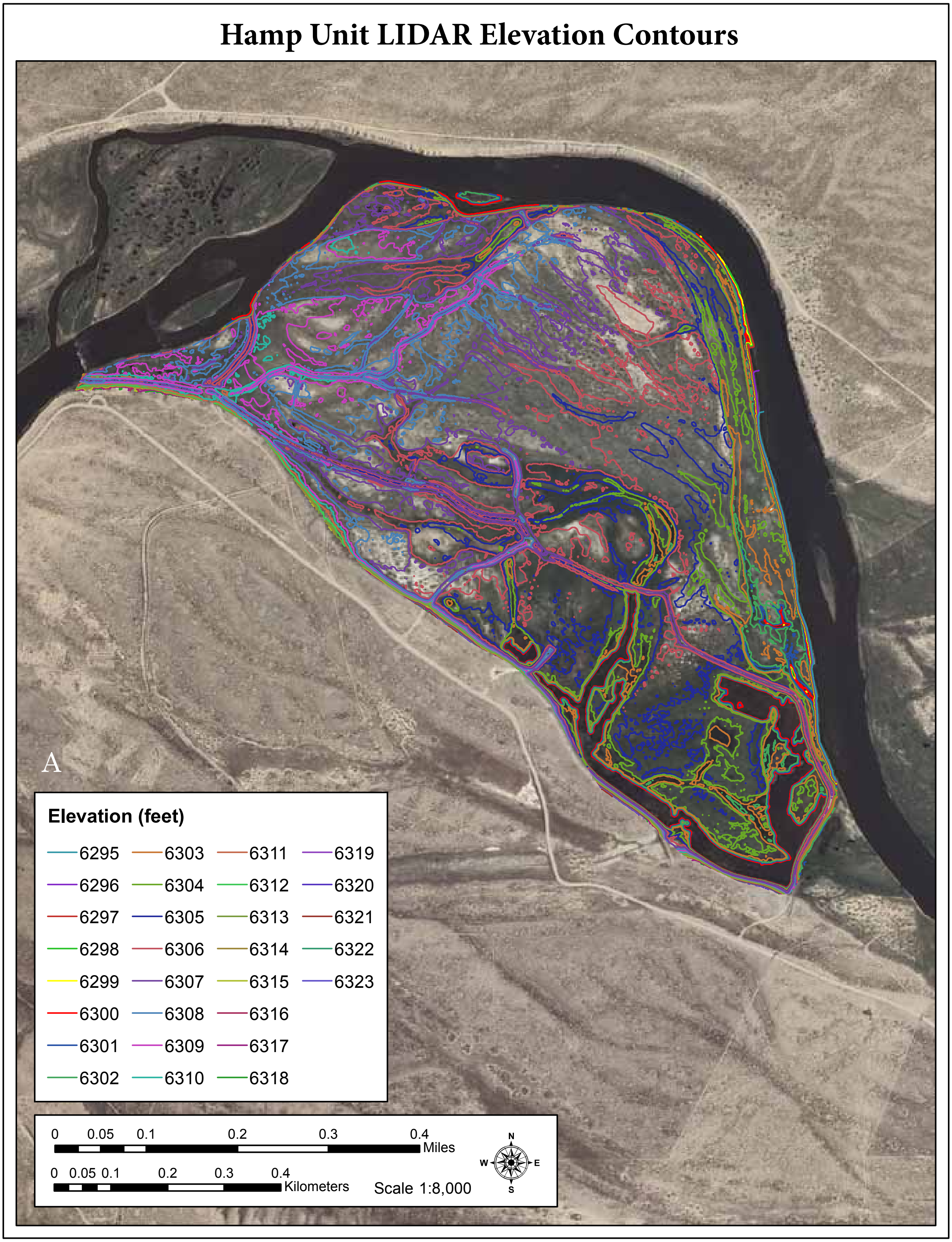


Figure 6. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

Hawley Unit LIDAR Elevation Contours

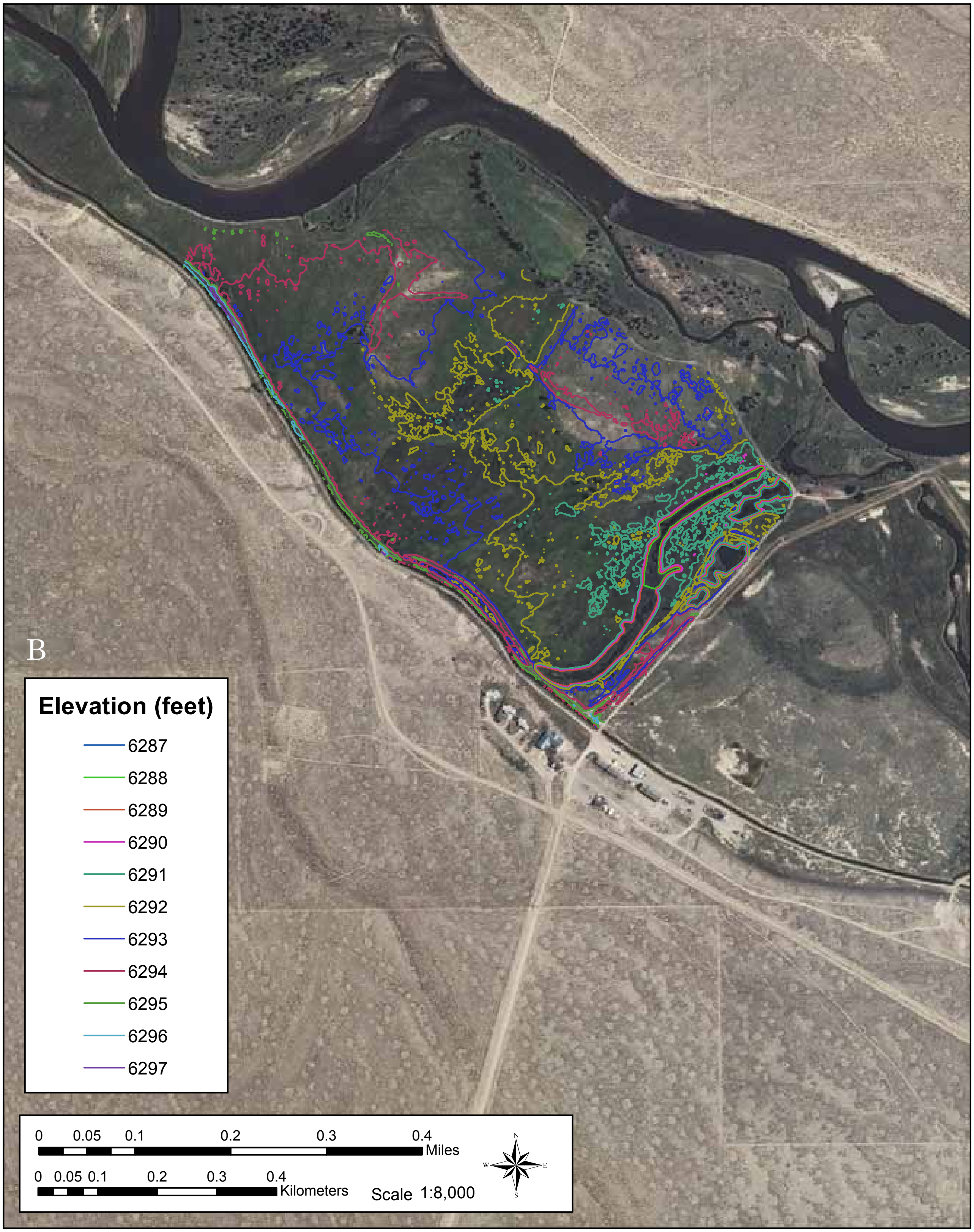


Figure 6, cont'd. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

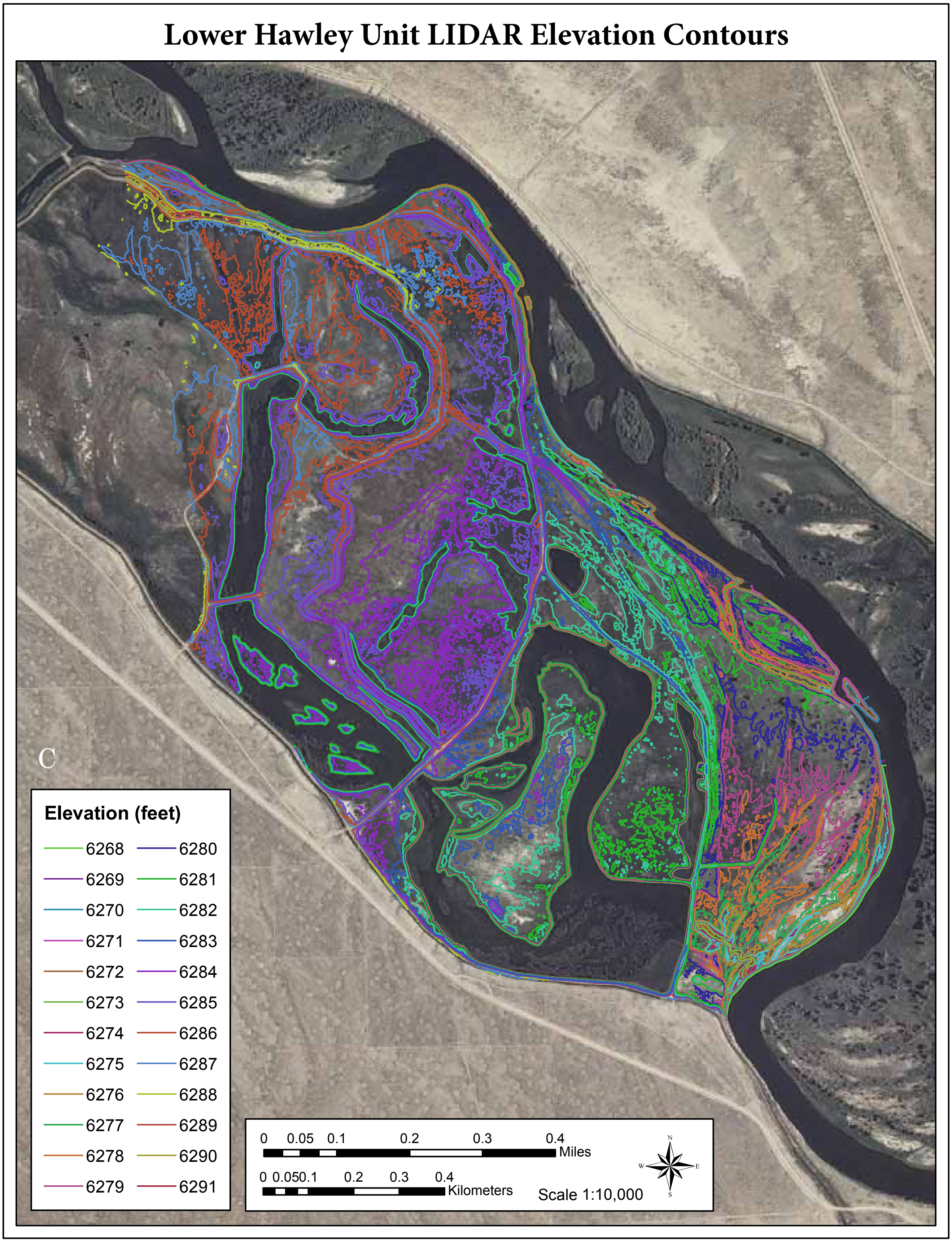


Figure 6, cont'd. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

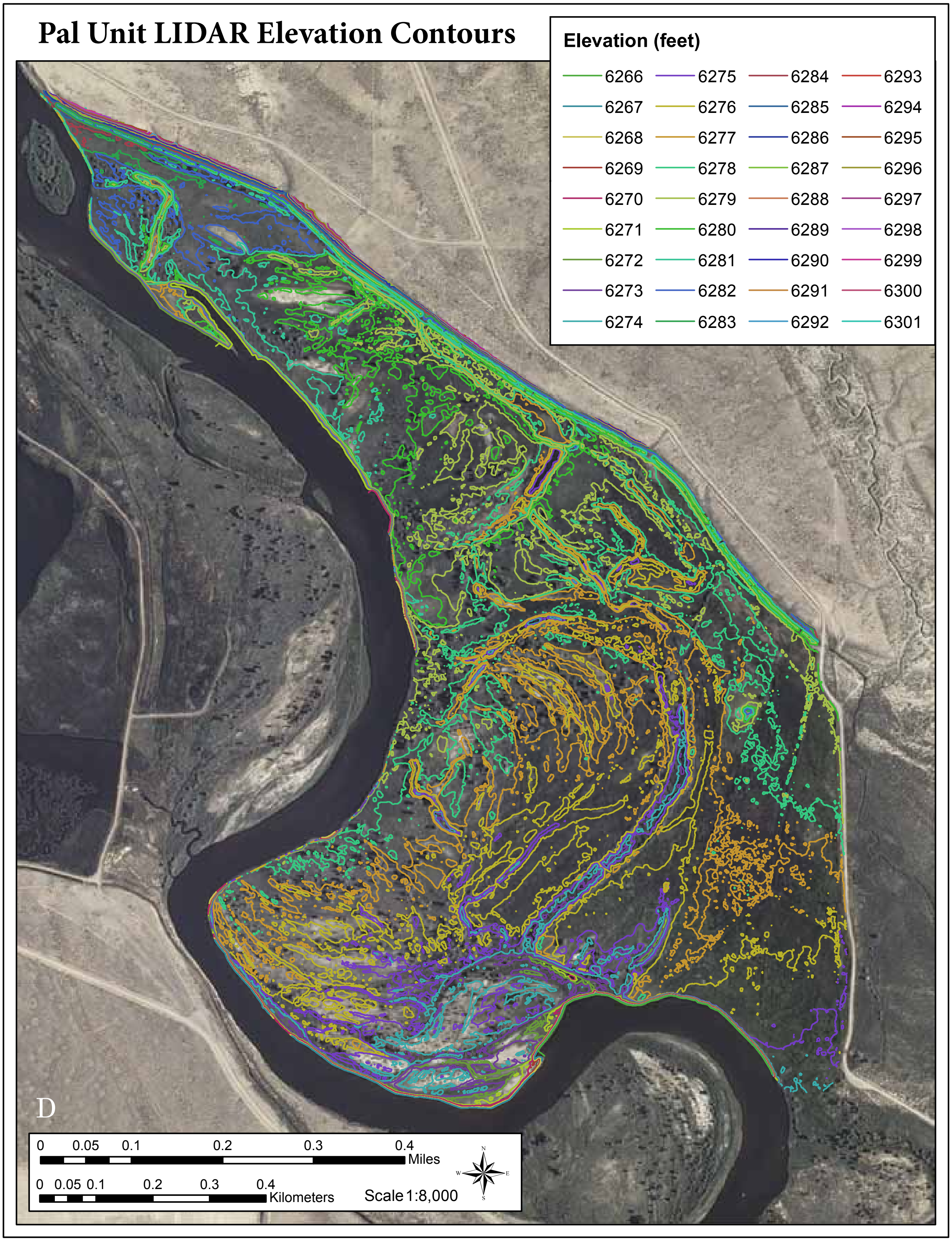


Figure 6, cont'd. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

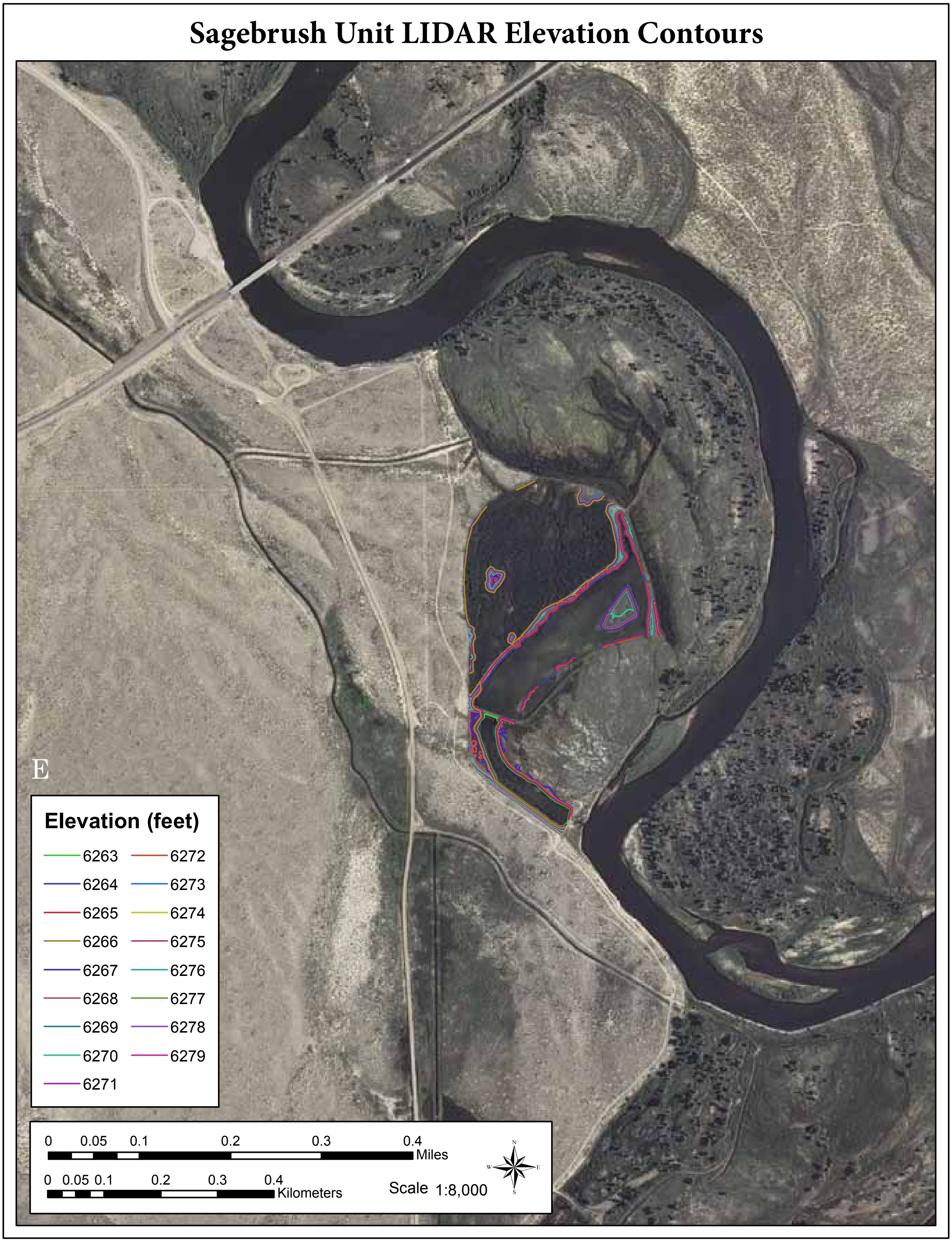


Figure 6, cont'd. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

Cottonwood Unit LIDAR Elevation Contours

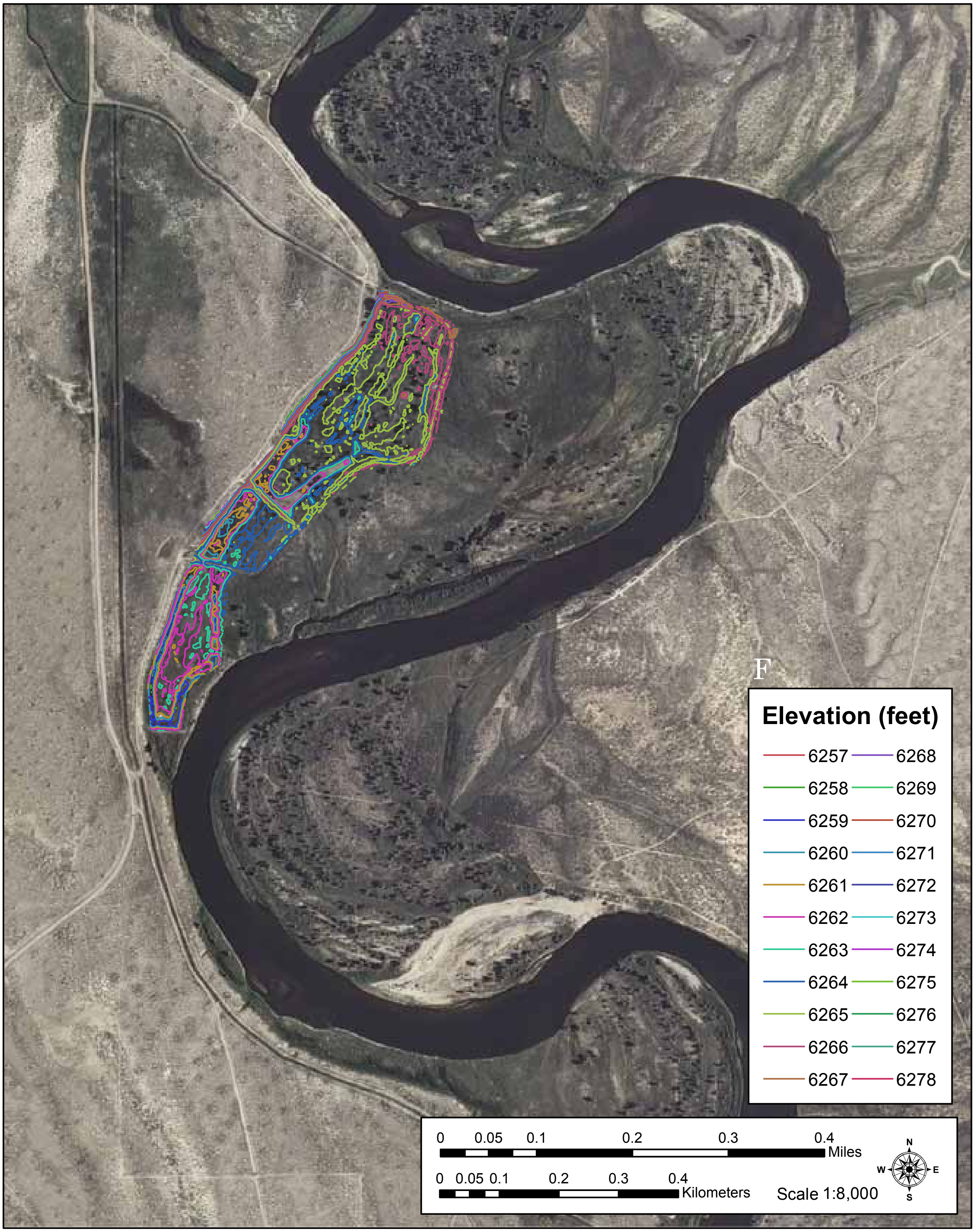


Figure 6, cont'd. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

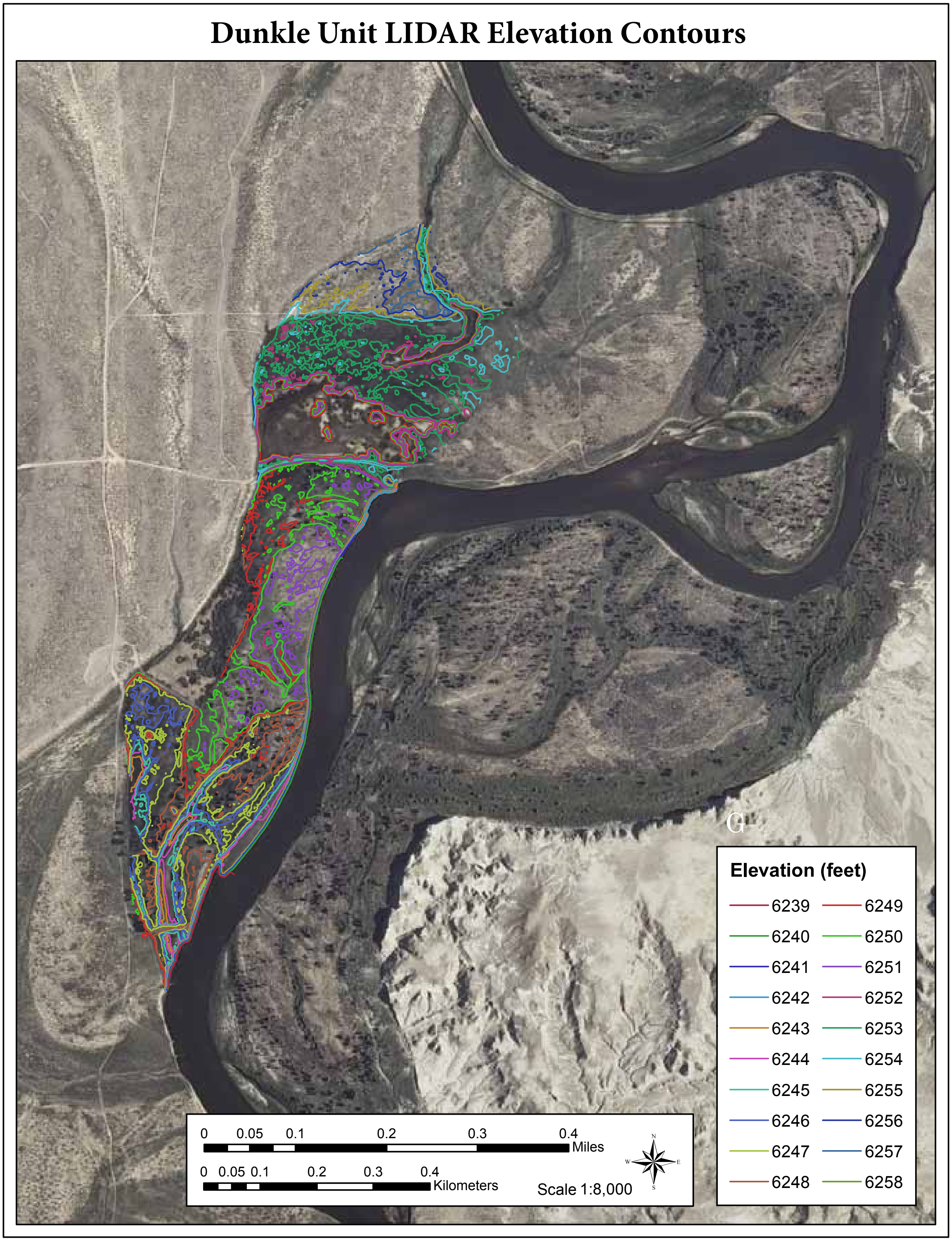


Figure 6, cont'd. LIDAR topographic contours (one foot) for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge.

Table 1. Upstream and downstream elevations for wetland units on Seedskadee National Wildlife Refuge, determined from LIDAR flown during 2010.

River Bend (near wetland unit)	Elevation (feet)	
	Low	High
Hamp	6295	6323
Hawley	6287	6297
Lower Hawley	6268	6291
Pal	6266	6301
Sagebrush	6263	6279
Cottonwood	6257	6278
Dunkle	6239	6258

The best information on historical (pre-Fontenelle Reservoir) flows of the Green River near Seedskadee NWR come from three U.S. Geological Survey (USGS) stream gauge monitoring stations located upstream near Fontenelle, Wyoming (USGS #09209500) from1947-1965 and downstream (USGS #09216500 and #09217000) near Green River, Wyoming from 1896 to 1939 and 1953-63, respectively (Peterson 1988, Mason and Miller 2005). River discharge measurements at the Fontenelle gauge station (USGS #09209500) are equivalent to published river level and discharge readings near La Barge, Wyoming (USGS #09209400) after March 1965, when the Fontenelle station was discontinued. Mean annual Green River flows upstream of Seedskadee at station # 9209500 from 1947 to 1965 averaged 1,570 cfs with a peak mean monthly discharge of 5,650 cfs in June (Table 2, Fig. 9). The range in daily flows for this station prior to Fontenelle Reservoir was a maximum flow of 13,300 cfs in June 1956 and a minimum flow of 200 cfs in December 1962. Peak annual flows > 10,000 cfs (a level of some backwater flooding in the Seedskadee Floodplain – see below) occurred in 9 of 19 years (47%) from 1947 to 1965 (Fig. 10). During this time flows > 8,490 cfs for at least 7 consecutive days occurred at a 50% yearly occurrence (i.e., on average every 2 years); flows > 10,600 cfs for at least 7 consecutive days occurred at a 20% yearly occurrence (i.e., on average every 5 years); and flows > 11,600 cfs for at least 7 consecutive days occurred at a 10% yearly occurrence (i.e., on average every 10 years) (Table 3). These data indicate that Green River flows capable of causing substantial flooding of the Seedskadee NWR floodplain was a common event.

Downstream at station #09216500 the mean annual flow of the Green River from 1896 to 1939 was 1,849 cfs with a mean peak monthly discharge of 6,921 cfs in June. This station and time period had a range in daily flow from 22,200 cfs in June 1918 and a low of < 100 cfs in 1935 (Table 4, Fig. 11). Peak flows at this station exceeded 10,000 cfs in 25 of 36 (69%) years with data during this period and flows > 15,000 cfs were exceeded 15,000 cfs in 9 of 36 (25%). At station #0921700 prior to construction of Fontenelle Reservoir, the mean annual discharge was 1,552 cfs, the peak mean monthly discharge was 5,466 cfs in June, and daily discharges ranged from 14,800 cfs in 1956 to a low of 170 cfs in 1955 (Table 5, Fig. 12). Green River flows at this station were > 10,000 cfs in 6 of 13 (46%) of the years from 1952 to 1963. Flows of 8,530; 11,300; and 12,700 cfs for at least 7 consecutive days occurred on average 50%, 20%, and 10% of the years, respectively (Table 6). The relative increase in Green River flow from Fontenelle to Green River, Wyoming reflects the entry of the Big Sandy River to the Green River below Eden, Wyoming where the mean annual inflow is 72.5 cfs and the mean peak monthly discharge is 145 cfs in June (Table 7).

Typically the Green River discharge at Seedskadee NWR historically began to gradually rise starting in April, peaked in early June, and gradually fell to low sustained levels from August through February or March. Both the average rising and falling limb of the annual hydrograph/discharge curve is about 1-2 cm/day, although individual years and events can cause rapid decline or rise of river levels. During the oldest period of record, 1896-1939, mean annual runoff from the Green River at Green River, Wyoming (USGS #09216500) was 1,339,000 acre-feet, with 30.8% of that occurring in June (Table 4). Average mean monthly discharge in June was 6,921cfs with a 90 percentile of 11,460 cfs. Prior to Fontenelle Reservoir, annual Green River runoff at Green River, Wyoming (USGS #09217000) during 1952-63 was 1,125,000 acre-feet and ca. 60% of the mean annual runoff occurred in May, June, and July (Table 5). Runoff from the Big Sandy River at Gasson Bridge near Eden, Wyoming (USGS #09216050) from 1973 to 2002 averaged only 52,540 acre-feet and peak runoff occurs slightly earlier than in the Green River, with about 22% of mean annual runoff occurring in March and April and only 37% occurring from May to July (Table 7).

Mean annual and yearly peak discharge of the Green River near Green River, Wyoming has varied widely among years, dating to 1895, especially

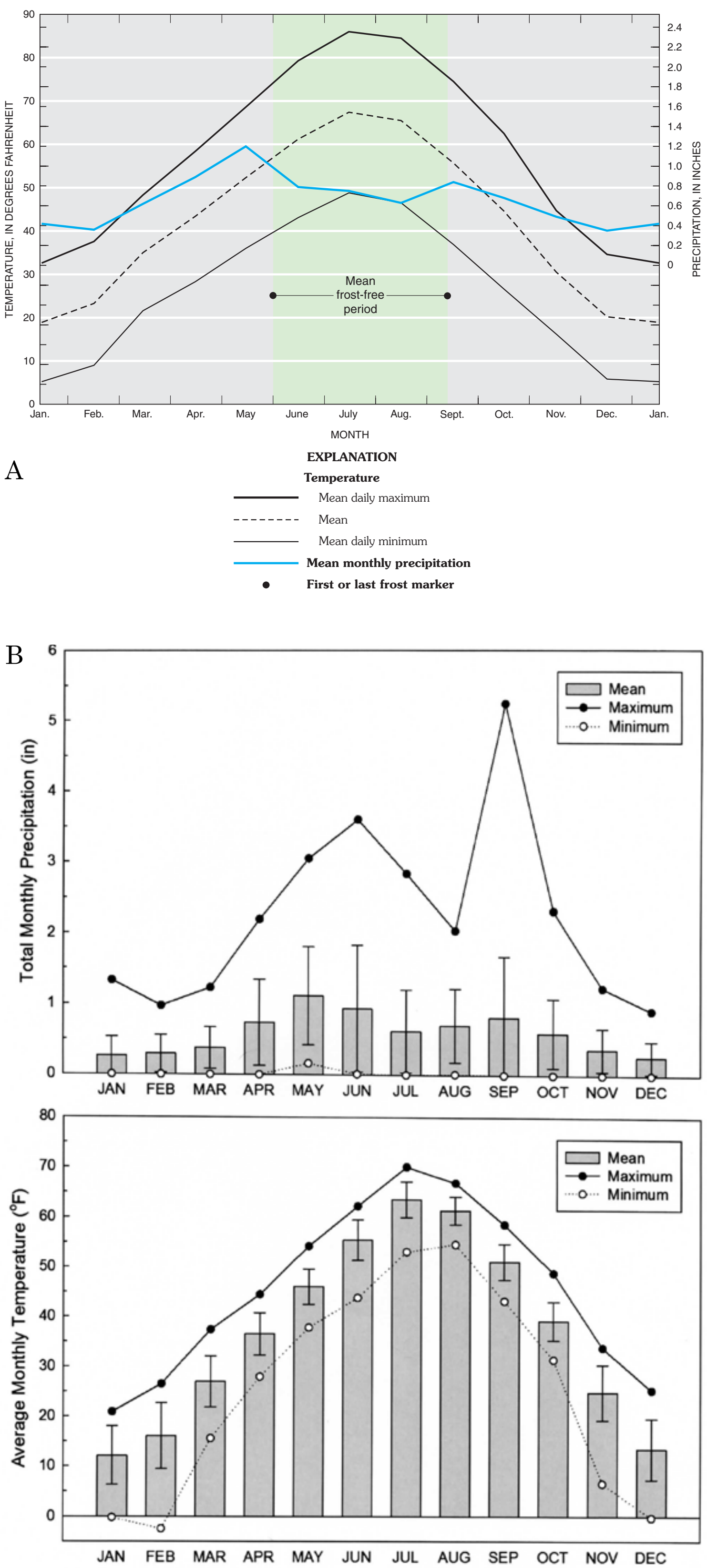


Figure 7. Mean a) daily precipitation and b) monthly precipitation and temperature for the Seedskadee National Wildlife Refuge region (compiled from Western Regional Climate Center, Fontenelle Station data, http://www.wrcc.dri.edu).

prior to construction of Flaming Gorge and Fontenelle Dam (Figs. 10-12, Tables 2-7). Historically, a discharge of > 10,000 cfs occurred in about 50% of all years and discharges of at least 15,000 cfs occurred in about every 4-5 years. Flood events of > 20,000 cfs were rare at locations north of Seedskadee, but occurred in 3 of 36 years at Green River, Wyoming from 1898 to 1922 (Fig. 11). Annual peak flooding discharges of >10,000 cfs probably were of relatively short duration in most years historically as suggested by percentage of time a discharge of > 10,000 cfs historically occurred for consecutive days (Tables 3, 6). For example 7 days of consecutive flooding > 10,000 cfs occurred only 20% of years at both Fontenelle and Green River for the period of records (pre-Fontenelle Reservoir) for these stations. Nonetheless, even a short duration flood would have inundated depressions, and surface water would have been recharged and been held in deeper depressions not directly connected to the river channel.

No long-term gauge station for the Green River is present on Seedskadee NWR proper. Consequently, the stage-discharge relationship for river discharge vs. elevation of flooding on the refuge lands is unknown. The official "flood stage", when significant overbank flooding occurs at Green River, Wyoming is 15,000 cfs; the National Weather Service issues flood warnings, with some predicted backwater flooding of low sloughs and floodplain depressions, at 12,700 cfs. Observations by refuge personnel (Carl Millegan, personal communication) indicate that a discharge of about 8,000 to10,000 cfs below Fontenelle Reservoir causes water from the Green River to enter low elevation "cuts" or "swales" in some floodplain bottoms on Seedskadee NWR. In June 2011, a discharge of ca. 8,700 cfs below Fontenelle Dam caused water to back from the Green River into old river channels, sloughs, and low elevation swales on parts of Seedskadee NWR. Further, aerial photographs indicate widespread flooding of Seedskadee floodplains in September 1965 when a river discharge of about 16,800 cfs occurred (Fig. 13). These 1965 photographs are important because they occurred prior to most levee and water-control infrastructure developments on Seedskadee NWR. Past observation by refuge personnel also indicate that discharges of about 500 cfs in the Big Sandy River causes initial backwater flooding and discharges of 2-3,000 cfs cause widespread flooding of the Big Sandy River floodplain. Estimates of bankfull flow of the Green River at select sites on Seedskadee in the early 2000s, using Manning's equation for discharge calculations, ranged from 237 to 1,524 m^3/second, which is equivalent to 8,368 to 29,131 cfs (Glass 2002). This variation in bankfull measurements reflects the large topographic heterogeneity along the Green River at Seedskadee NWR (see Figs. 5,6), but also indicates that discharge levels of > 8,000 cfs are capable of producing some backwater flooding into floodplain swales and depressions. Further, these data suggest extreme flood flows of 20,000 cfs are capable of flooding most areas in the contemporary Green River floodplain.

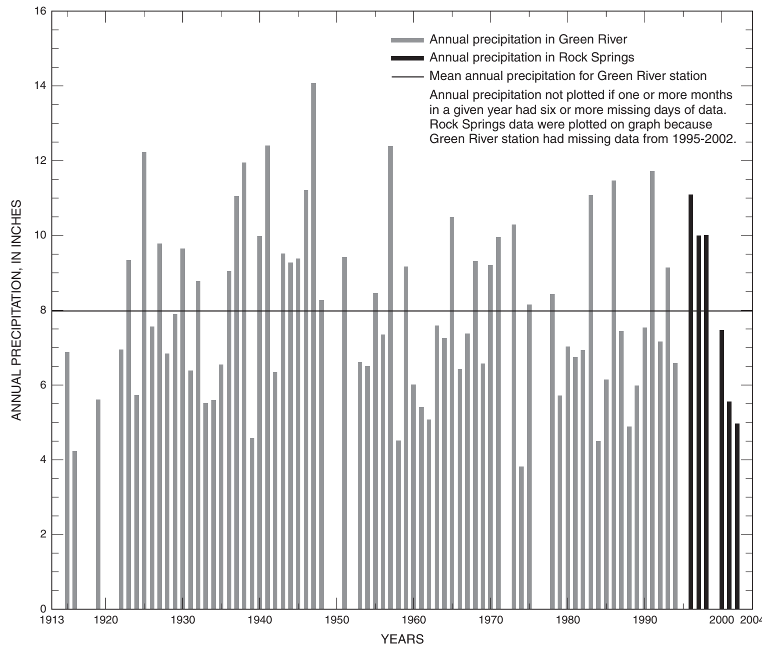


Figure 8. Total annual precipitation for Green River and Rock Springs, Wyoming 1913 to 2004 (from Mason and Miller 2005).

Rough estimates of the stage-discharge relationship of the Green River immediately below Fontenelle Reservoir (Fig. 14) suggest that river stage height rises about 5.6 inches per 1000 cfs increase, at least up to about 14,000 cfs total (Auble et al. 1997). This equates to about a one foot rise in water level per 2,142 cfs increase in discharge. At higher discharges, the curve flattens and becomes non-linear as surface area of channels and flows into floodplains increases. Consequently, relative increases in flooded area in Green River floodplains relative to larger increases in river discharge are unknown. Nonetheless, at the levels of historic first flooding into Seedskadee NWR floodplains, it seems reasonable to suggest that after initial entry of backwater into the floodplain, the elevation increments of additional flooding are in the range of one foot increase in flood water height and inundation per 2,000 cfs increase in discharge up to about 14,000 cfs and then the relationship flattens to about one foot increase in water levels per 3,000+ cfs increase in discharge, thereafter. This assumption seems at least partly supported by the fact that the current distribution of cottonwood in the Green River floodplain below Fontenelle Dam, most of which became established in the mid-late 1800s presumably with flood flows of ca. 20,000 cfs (Glass 2002, Fig. 11) are 3-8 feet above base flows of 2,000 cfs in the Green River (Auble and Scott 1998). Further, current cottonwood stands BD 92 and BD 94 near the old Lombard Ferry location on Seedskadee NWR are at

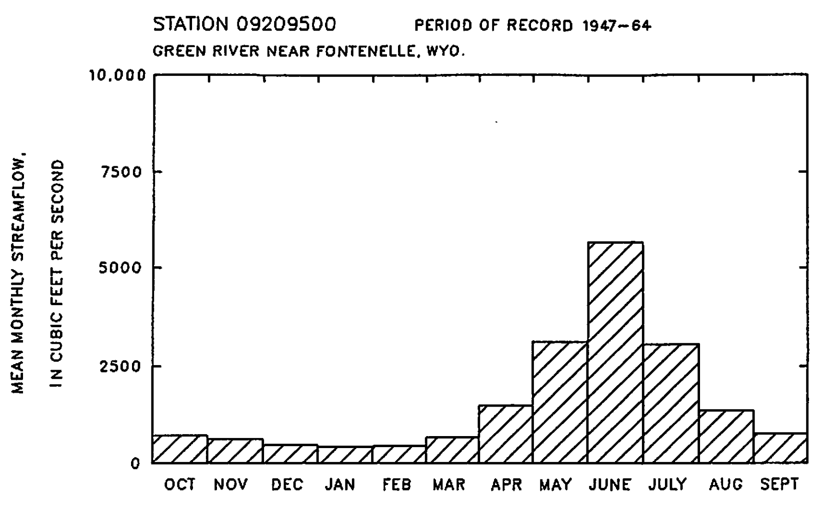


Figure 9. Mean monthly streamflow (cfs) for the Green River at Fontenelle, Wyoming, USGS gauge station #09209500, 1947-1964 (from Peterson 1988).

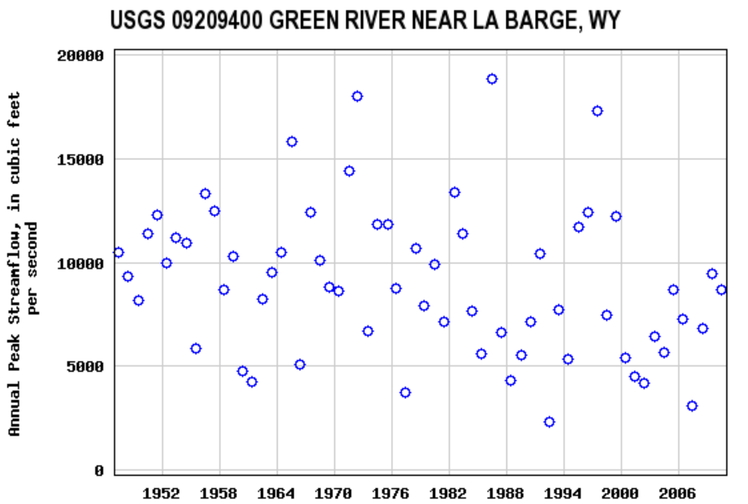


Figure 10. Peak streamflow for the Green River near LaBarge, Wyoming 1947-2010 (from http://waterdata.usgs.gov/nwis/peak).

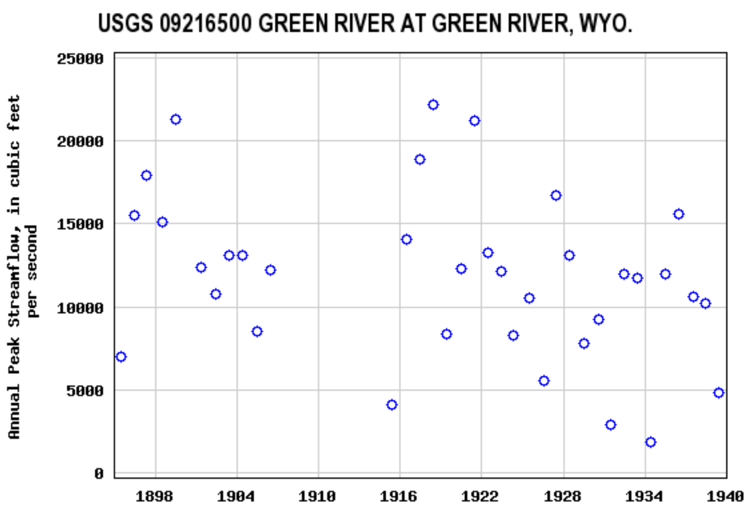


Figure 11. Peak streamflow for the Green River near Green River, Wyoming 1895-1940 (from http://waterdata.usgs.gov/nwis/peak).

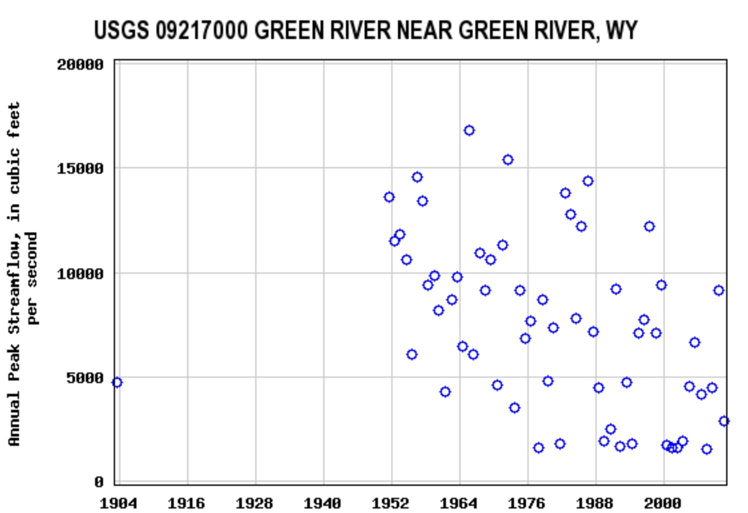


Figure 12. Peak streamflow for the Green River near Green River, Wyoming 1952-2010 (from http://waterdata.usgs.gov/nwis/peak).

elevations 6,276 and 6,268 feet amsl, which are about 6-7 feet above the low elevation entry point of floodplain swales off the Green River channel where floodwaters first enter the floodplain (Fig. 15).

We modeled the potential area flooded by different levels of Green River discharge for the floodplain bends that contain constructed wetland impoundments on Seedskadee NWR prior to major infrastructure developments on the refuge (Fig. 16). These seven areas were chosen because they have been highly modified by levees, water diversions, and water-control structures and management questions exist about restoration potential. Flood models were completed using visual estimates of the distribution of historical flooding and hydraulic analysis with HEC-RAS (Brunner 2010). HEC-RAS models of potential area flooded included the entire reach of the Green River within the boundary of Seedskadee NWR (Fig. 17).

Visually estimated flood distribution models were based on the following assumptions:

1. The current low elevation contour lines in abandoned channels, high flow channels, and seasonally connected sloughs in Seedskadee NWR floodplains (e.g., Fig. 6) represent the point of first inundation by Green River flows of 8,000 to 10,000 cfs. This assumption seems confirmed by observations of river backwater locations during June 2011 when river discharge was about 8,700 cfs.

2. Stage-discharge relationships at Seedskadee are a one foot rise in flood water level per 2,000 cfs increase in discharge up to 14,000 cfs and then one foot flood water rise per 3,000 cfs increase in discharge up to 20,000 cfs. This assumption is based on Fig. 14, the above discussion of cottonwood locations, and observed inundated

area in September 1965 when the Green River discharge was about 16,800 cfs and no water-control infrastructure was present.

3. By determining the elevation (from LIDAR maps) of surface water during the 1965 flood (Fig. 13) then elevation contours correlated with increased flows to 20,000 cfs (one foot elevation rise/3,000 cfs increase from assumption #2 above), 14,000 cfs (one foot elevation decline/3,000 cfs decrease), 12,000 cfs (one foot elevation decline/2,000 cfs decrease), and 10,000 cfs (one foot elevation decline/2,000 cfs decrease) can be mapped.

4. The LIDAR surveys flown in 2010 adequately represent topographic conditions (excepting current water-control levees and other infrastructure) present before the 1970s.

5. The area of flood inundation mapped for each unit only applies to that location because this method does not account for the slope of the Green River.

Hydraulic analysis with HEC-RAS was based on the following methods and assumptions:

1. The analysis is limited to the steady flow water surface profile computations, which computes water surface elevation for a constant flow rate at all points in the river. Multiple flow rates were analyzed, however only one flow rate was analyzed in each model run, rather than changing the flow rate at different points along the river.

2. The computational procedure is based on the solution of the one-dimensional energy equation. This procedure calculates energy losses using Manning's equation and contraction/expansion. Manning's equation is dependent on: 1) the cross-sectional shape of the river, 2) the surface roughness of the river channel, and 3) the slope of the water surface.

3. The cross-sectional area of the floodplain can be accurately modeled only for the areas that were above water at the time the LIDAR survey was flown. LIDAR does not penetrate water so the cross-sectional area of the river beneath the water surface was estimated by modifying the LIDAR data in ArcMap. This was accomplished by first identifying the edge of the water. The line defining the edge of the water was then offset toward the middle of the river by a distance of 3 m (9.8 feet) horizontally on both sides of the river. All LIDAR points between this offset line and the water edge were lowered 0.3 m (1 foot). Next, the line defining the edge of the water was offset towards the middle of the river by 5 m (16.4 feet) horizontally on both sides of the river. All

Table 2. Monthly and annual stream flow of the Green River, 1947-64 for USGS gauge station #09209500 near Fontenelle, Wyoming (from Peterson 1988).

Month	Maximum (ft^3/s)	Minimum (ft^3/s)	Mean (ft^3/s)	Standard deviation (ft^3/s)	Coefficient of variation	Percent of annual runoff
October	1040	476	715	188	0.26	3.80
November	1010	389	628	176	0.28	3.30
December	723	281	480	130	0.27	2.50
January	622	275	424	103	0.24	2.20
February	726	320	461	122	0.26	2.40
March	1230	428	674	197	0.29	3.60
April	3160	777	1510	724	0.48	8.00
May	5290	1040	3130	1470	0.47	16.60
June	8760	2690	5650	1770	0.31	30.00
July	6060	751	3060	1620	0.53	16.20
August	3010	579	1370	627	0.46	7.30
September	1310	467	768	270	0.35	4.10
Annual	2420	791	1570	472	0.30	100.00

Table 3. Magnitude and probability of annual high flow based for the Green River near Fontenelle, Wyoming 1947-64 (USGS gauge station #09209500) (from Peterson 1988).

Period (consecutive days)	Discharge, in ft^3/s, for indicated recurrence interval, in years, and exceedance probability, in percent					
	2 - 50%	5 - 20%	10 - 10%	25 - 4%	50 - 2%	100 - 1%
1	9600	11700	12600	13300	--	--
3	9270	11400	12300	13100	--	--
7	8490	10600	11600	12500	--	--
15	7410	9230	10100	10900	--	--
30	6110	7840	8750	9700	--	--
60	4930	6400	7100	7780	--	--
90	4020	5340	6010	6680	--	--

Table 4. Monthly and annual streamflow of the Green River, 1896-1939 for USGS gauge station #09216500 near Green River, Wyoming (from Mason and Miller 2005).

Month or annual	Water year			Streamflow, in cubic feet per second				Coefficient of variation (unitless)	Percentiles, in cubic feet per second					Mean runoff	
	Begin	End	Total	Maximum	Minimum	Mean	Standard deviation		10th	25th	50th	75th	90th	Acre-feet	Percent of annual
10	1896	1939	35	1,505	314	770	323	0.42	374	534	724	937	1,243	47,360	3.54
11	1896	1939	35	1,330	265	624	215	.34	387	473	608	755	849	37,130	2.77
12	1896	1939	35	700	260	461	121	.26	296	375	475	550	608	28,360	2.12
1	1896	1939	35	650	250	384	96.4	.25	271	302	360	450	500	23,580	1.76
2	1896	1939	35	700	250	408	101	.25	300	350	400	440	530	22,880	1.71
3	1896	1939	35	1,973	300	805	413	.51	444	531	656	938	1,440	49,480	3.69
4	1896	1939	35	2,924	376	1,778	675	.38	984	1,265	1,801	2,321	2,655	105,800	7.90
5	1896	1939	35	9,774	1,058	3,685	1,901	.52	1,396	2,418	3,394	4,575	6,217	226,600	16.9
6	1896	1939	35	13,430	846	6,921	3,277	.47	2,840	4,967	6,827	8,972	11,460	411,900	30.8
7	1896	1939	35	14,540	430	3,804	2,622	.69	1,661	2,517	3,460	4,449	5,379	233,900	17.5
8	1896	1939	35	5,169	476	1,589	872	.55	725	1,121	1,417	1,929	2,205	97,680	7.29
9	1896	1939	35	2,061	258	918	414	.45	471	635	890	1,223	1,311	54,650	4.08
ANNUAL	1896	1939	35	3,458	528	1,849	608	.33	1,140	1,456	1,859	2,230	2,459	1,339,000	100

Table 5. Monthly and annual streamflow of the Green River prior to construction of Fontenelle Reservoir 1952-1963 (from Mason and Miller 2005).

Month or annual	Water year			Streamflow, in cubic feet per second				Coefficient of variation (unitless)	Percentiles, in cubic feet per second					Mean runoff	
	Begin	End	Total	Maximum	Minimum	Mean	Standard deviation		10th	25th	50th	75th	90th	Acre-feet	Percent of annual
10	1952	1963	12	1,310	531	726	239	0.33	538	565	662	724	1,053	44,660	3.97
11	1952	1963	12	845	457	630	134	.21	475	525	602	732	804	37,460	3.33
12	1952	1963	12	703	288	476	118	.25	389	418	438	524	661	29,270	2.60
1	1952	1963	12	670	287	450	121	.27	319	356	432	526	600	27,690	2.46
2	1952	1963	12	868	324	546	192	.35	348	386	494	680	837	30,610	2.72
3	1952	1963	12	1,475	482	878	297	.34	556	707	811	999	1,252	53,990	4.80
4	1952	1963	12	3,416	842	1,693	893	.53	870	1,176	1,351	1,920	3,147	100,800	8.96
5	1952	1963	12	5,665	978	2,940	1,776	.60	1,092	1,262	2,467	4,615	5,004	180,800	16.1
6	1952	1963	12	9,322	2,718	5,466	1,987	.36	3,003	4,057	5,537	6,478	7,878	325,200	28.9
7	1952	1963	12	6,184	757	2,770	1,535	.55	1,115	1,732	2,547	3,535	4,066	170,300	15.2
8	1952	1963	12	1,795	575	1,273	415	.33	642	1,041	1,339	1,605	1,686	78,260	6.96
9	1952	1963	12	1,300	462	764	245	.32	583	635	676	826	1,117	45,480	4.04
ANNUAL	1952	1963	12	2,218	799	1,552	474	.31	986	1,250	1,514	2,015	2,156	1,125,000	100

LIDAR points between these offset lines were lowered a distance of 1 m.

4. The water surface across a cross-section of the river was assumed to be constant. The effects of hydraulic features such as levees and bridges were not modeled because the output of the HEC-RAS model was similar to historical flooding events.

5. The surface roughness of the river channel, also known as Manning's Value, varies greatly along a river reach and with different stages of flow. For example, channels with heavy vegetation have more surface roughness than a channel lined with short grass. The roughness of a channel can also vary through the year as vegetation type and height changes. For this modeling effort, Manning's value for the channel was set at 0.039. Manning's value for the floodplain was set to 0.05.

6. Water surface profile results created by HEC-RAS were processed to visualize inundation boundaries (Ackerman 2009).

Further explanation of the HEC-RAS model methods used in this report, and an example of analyses for the Lower Hawley Unit is provided in Appendix A to illustrate the uses of the procedure and its limitations.

The modeled distribution of flood inundation was similar between the visual and HEC-RAS methods in areas where water-control infrastructure developments were limited (e.g., Fig. 16d). Results for the two methods varied the most in areas where extensive dike construction has occurred and/or in areas that were flooded when the LIDAR was flown (e.g., Fig. 16c). These potential flood inundation maps can be improved in the future if: 1) more information becomes available about stage-discharge relationships along the Green River below Fontenelle Reservoir, 2) the cross-sectional profiles of the Green River and other areas flooded when the LIDAR was flown are surveyed and mapped, 3) surface roughness is measured during flood events, and 4) future flood events of different levels > 10,000 cfs occur and area flooded can be mapped. HEC-RAS models also could be improved by modeling the effects of hydraulic features such as levees, bridges, and varied and split flows in the river.

Despite some limitations, the potential flood inundation maps suggest interesting patterns of flood frequency based on location in the floodplain, past river migration routes and resulting topography, and river stage. Typically, floodwaters tend to enter floodplain bottoms in the Upper Green River from the downstream end of point bars (e.g., Fig. 16d, see also Fig. 18), inundate old river channel corridors and swales first and most extensively, and then floodwaters gradually shallowly flood higher swales and terraces. At higher discharge levels (usually > 14,000 cfs) river water then begins to overtop upstream river bend areas and natural levees and connect flood waters with downstream backwaters (see e.g., Fig. 16e).

While most of the surface water hydrology of the Seedskadee NWR region is driven by annual snowmelt runoff into the Green River, groundwater discharge from aquifers also contributes small amounts of surface water to the ecosystem. All major streams in the Green River Structural Basin, including the Green River and Big Sandy River are gaining streams that receive some groundwater discharge into the drainages that support base flows (Fig. 19). Groundwater in the Green River Basin occurs within both unconsolidated alluvial deposits and in the deeper bedrock formations and has a wide range of variability in quality and quantity. Groundwater originates, or is recharged, when rainfall, snowmelt, streamflow, and now in some areas, irrigation water infiltrates into geological materials. Over time the groundwater travels through the subsurface and returns to the surface as discharge. Between the points of recharge and discharge, groundwater flow in the Green River Basin can be very complex (WWC Engineering et al. 2010). Because groundwater is returning to the surface as springs or seeps, it creates "gains" to the perennial Green and Big Sandy rivers.

Table 6. Magnitude and probability of annual high flow based for the Green River near Green River, Wyoming 1952-63 (USGS gauge station #09217000) (from Peterson 1988).

Period (consecutive days)	Discharge, in ft^3/s, for indicated recurrence interval, in years, and exceedance probability, in percent					
	2 - 50%	5 - 20%	10 - 10%	25 - 4%	50 - 2%	100 - 1%
1	9310	12300	13800	--	--	--
3	9090	12100	13500	--	--	--
7	8530	11300	12700	--	--	--
15	7360	9820	11200	--	--	--
30	5870	7950	9150	--	--	--
60	4610	6270	7150	--	--	--
90	3780	5220	6000	--	--	--

Table 7. Monthly and annual streamflow of the Big Sandy River 1972-2000 for USGS gauge station #09216050 near Eden, Wyoming (from Mason and Miller 2005).

Month or annual	Water year			Streamflow, in cubic feet per second				Coefficient of variation (unitless)	Percentiles, in cubic feet per second					Mean runoff	
	Begin	End	Total	Maximum	Minimum	Mean	Standard deviation		10th	25th	50th	75th	90th	Acre-feet	Percent of annual
10	1973	2002	30	102	25.8	60.7	16.5	0.27	43.0	52.0	60.7	70.1	83.8	3,730	7.10
11	1973	2002	30	149	27.0	53.3	21.6	.40	34.9	41.9	51.0	58.5	67.1	3,172	6.04
12	1973	2002	30	60.4	12.3	37.7	11.6	.31	23.4	30.9	38.2	45.0	51.4	2,318	4.41
1	1973	2002	30	55.5	10.6	30.6	9.16	.30	19.4	24.0	30.4	36.4	40.5	1,880	3.58
2	1973	2002	30	74.0	13.2	33.2	12.2	.37	21.3	25.1	32.6	38.2	43.4	1,859	3.54
3	1973	2002	30	393	32.7	84.2	72.8	.86	39.4	43.3	62.4	88.8	117	5,176	9.85
4	1973	2002	30	462	28.3	109	93.5	.86	44.8	51.9	75.2	140	184	6,464	12.3
5	1972	2002	31	208	19.8	76.0	49.3	.65	28.8	42.7	56.9	95.9	151	4,671	8.89
6	1972	2002	31	627	25.0	145	156	1.08	33.4	51.6	81.1	152	447	8,605	16.4
7	1972	2002	31	340	21.8	104	74.9	.72	36.4	59.6	89.1	116	204	6,420	12.2
8	1972	2002	31	119	23.0	77.7	26.3	.34	39.4	58.4	80.6	96.3	103	4,779	9.10
9	1972	2002	31	100	20.7	71.0	21.7	.31	42.2	53.9	75.8	88.8	95.1	4,222	8.04
ANNUAL	1973	2002	30	140	24.6	72.5	32.7	.45	35.0	47.8	65.2	90.6	117	52,540	100

Figure 13a

Hamp Unit - September 10, 1965

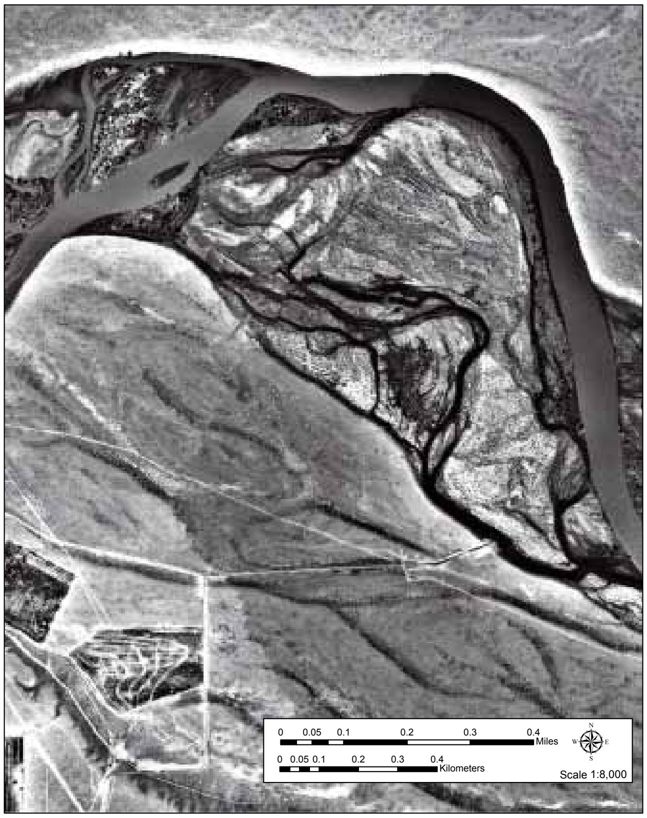


Figure 13b

Hawley Unit - September 10, 1965

Figure 13c

Lower Hawley Unit

Figure 13d

Pal Unit - September 10, 1965

Figure 13. Aerial photographs of select Seedskadee NWR floodplain areas showing the extent of flooding during a flood event of 16,800 cfs in September 1965.

Sagebrush Unit - September 10, 1965

Cottonwood Unit - September 10, 1965

Dunkle Unit - September 10, 1965

Figure 13, cont'd. Aerial photographs of select Seedskadee NWR floodplain areas showing the extent of flooding during a flood event of 16,800 cfs in September 1965.

Consequently, these river streamflow records include varying amounts of groundwater discharge. In general, shallow groundwater flow (< 500 feet below the ground surface) follows subsurface geologic stratigraphy and is discharged to river drainages.

Four major regional deep aquifers are present in the Green River Basin and include the Cenozoic, Mesozoic, Paleozoic, and Precambrian systems. The Cenozoic aquifer is the youngest and includes unconsolidated gravel and sand alluvial deposits, tertiary sedimentary rocks such as sandstone, conglomerate, and conglomeratic sandstone, and coal beds. This system includes Quaternary-age sands and gravels associated with major river courses. The primary Quaternary aquifer at Seedskadee is from saturated alluvium and colluviums deposits that range in thickness up to 50 feet deep. At Seedskadee NWR, the depth to groundwater is highly correlated with discharge and stage of the Green River (Scott et al. 2008). Wells in alluvial aquifers yield < 10 gal/min, but in clean sand and gravel along streams wells can produce up to several hundred gal/min. The Tertiary and overlying Quaternary aquifers make

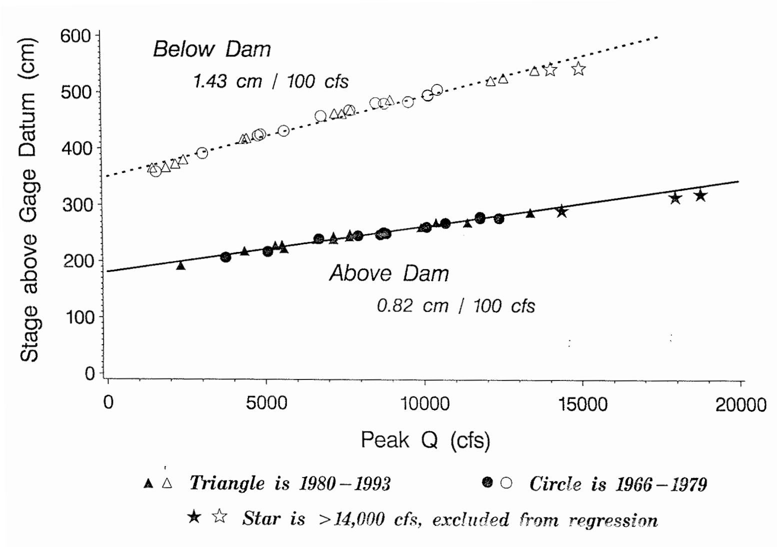


Figure 14. Stage-discharge relationships for the Green River near Fontenelle Reservoir (from Auble et al. 1997).

up 83% of the surficial geology of the Green River Basin and are the most abundant shallow aquifers in Sweetwater County; the Bridger and Green River Formations contain this aquifer. The older and deeper Mesozoic and Paleozoic aquifers are within water-bearing sandstone, conglomerate, and carbonate beds separated by confining shale units. The Precambrian system is comprised of old crystalline crustal rocks forming the deepest bedrock beneath the Basin and is only exposed at or near the surface in the cores of mountain uplifts at the rim of the Green River Basin.

Concentrations of dissolved constituents are low in the Green River because most flow in the river and its tributaries are derived from mountain snowmelt and because water runs across relatively resistant geological units, basin vegetative cover captures and uses water before it infiltrates deeper soil strata, and the relatively large annual runoff dilutes discharge concentrations (Mason and Miller 2005). Concentrations of dissolved constituents, suspended solids, and bacteria are higher in the smaller Big Sandy River system than in the Green River. Concentrations of dissolved solids in alluvial aquifers that contribute to base flows of the Green River also are relatively small. Groundwater quality tends to deteriorate with increasing distance from recharge areas and with increasing depths below the ground surface. Concentrations of dissolved solids are higher where groundwater discharges occur from the underlying Green River and Bridger Formations. Groundwater from depths of greater than a few thousand feet have total dissolved solid concentrations that make water moderately saline. In some areas, shallow groundwater discharge also is moderately saline.

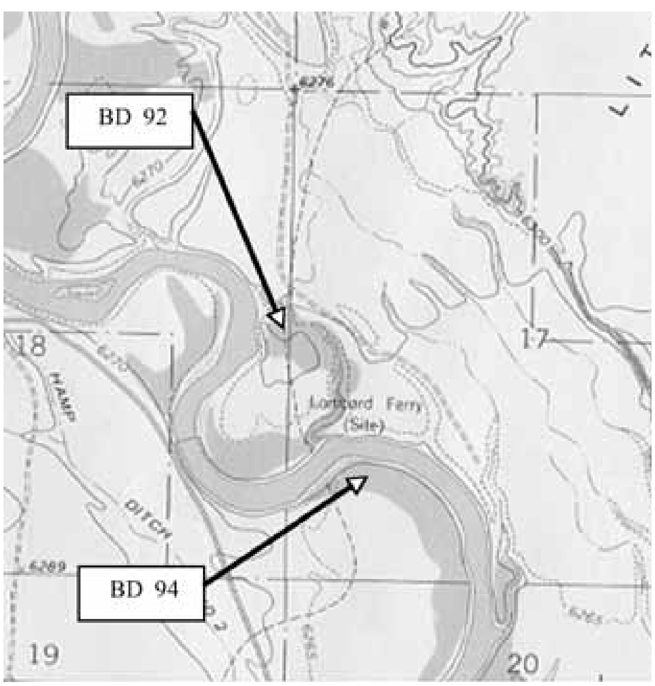


Figure 15. Location of two cottonwood stands on Seedskadee National Wildlife Refuge (from Glass 2002).

HISTORICAL PLANT AND ANIMAL COMMUNITIES

Seedskadee NWR contains relatively narrow (up to about 1.5 miles wide) floodplains along the Green and Big Sandy Rivers embedded within a sagebrush-dominated upland steppe landscape. The Green River is a sand-based sinuous channel system that has frequently meandered across the narrow floodplain. Historical channel movements created a heterogeneous topography (Fig. 6), that supported distinct vegetation communities, in abandoned channels, small oxbows, high flow braided scour channels, natural levee depositions, point bar meander scrolls, and other depressions (Fig. 20). The Green River Valley was visited by many early explorers, fur trappers, and pioneers, many of which recorded at least some vegetation features of the region (Nuttall 1834, Townsend 1839, Fremont 1845, Johnson and Winter 1846, Young 1899, Hafen and Hafen 1845). Common plant and

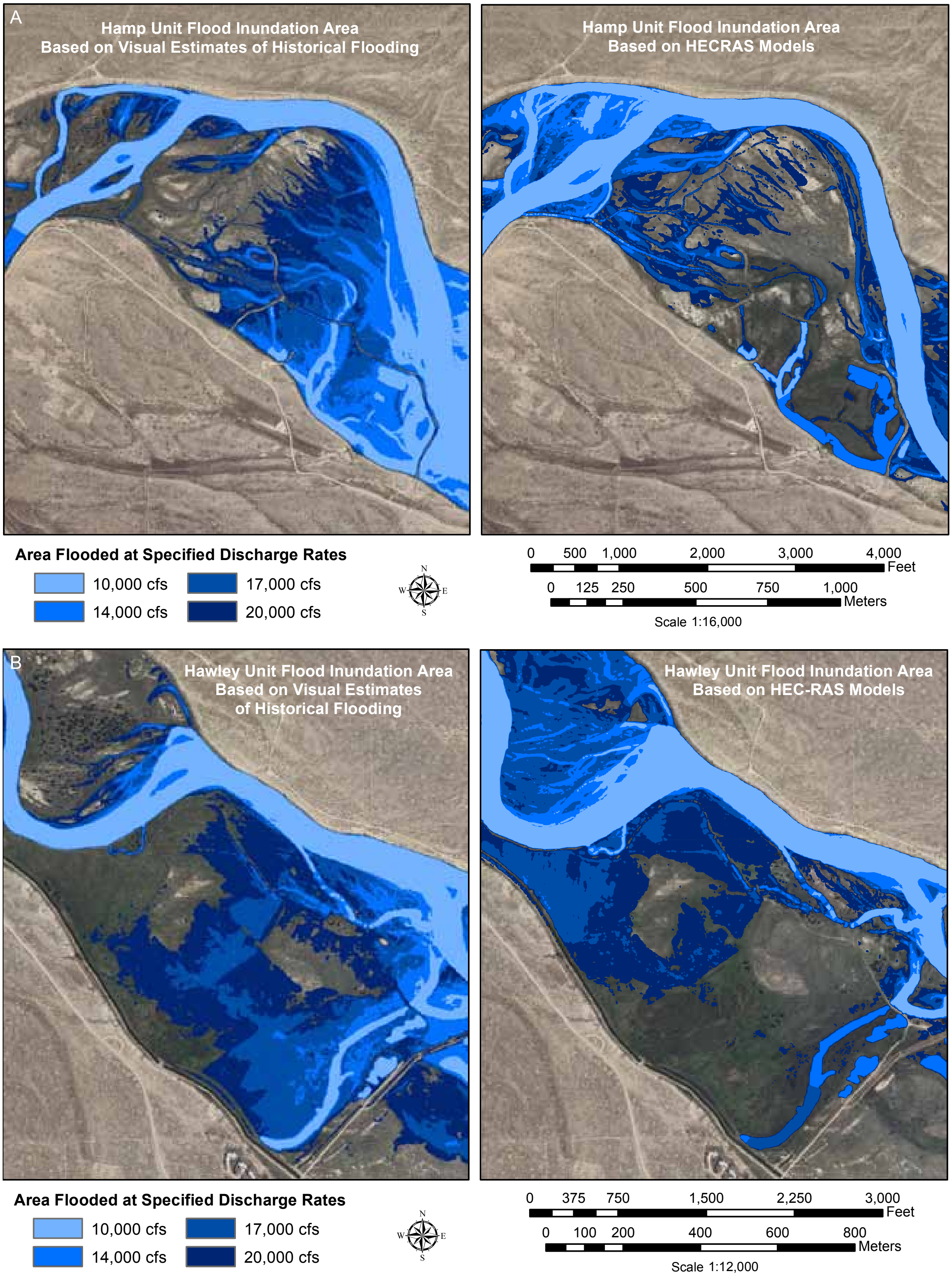
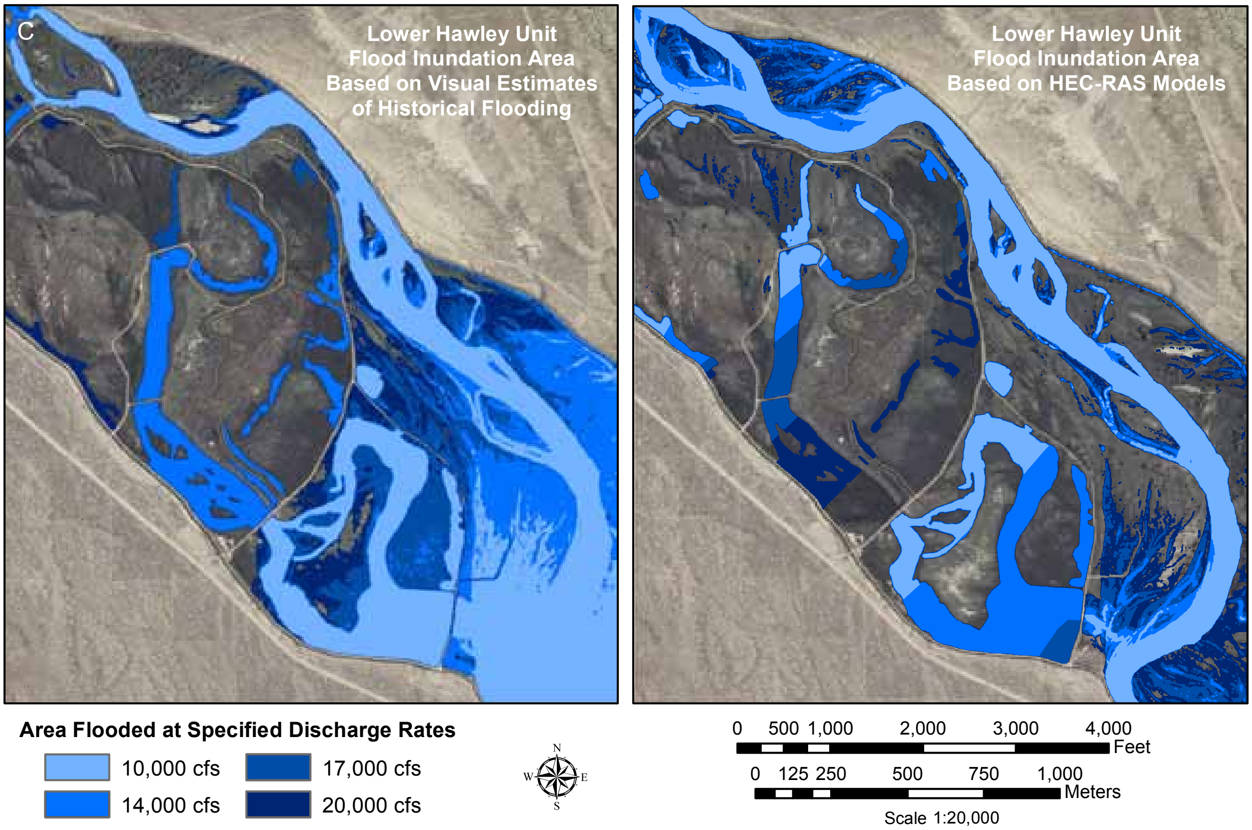


Figure 16. Estimated area potentially inundated for: a) Hamp, b) Hawley, c) Lower Hawley, d) Pal, e) Sagebrush, f) Cottonwood, and g) Dunkle wetland units on Seedskadee National Wildlife Refuge at Green River discharges of 10,000, 14,000, 17,000 and 20,000 cfs based on visual estimates of historical flooding and HEC-RAS hydraulic models (see text for explanation of methods).

Figure 16, cont'd.



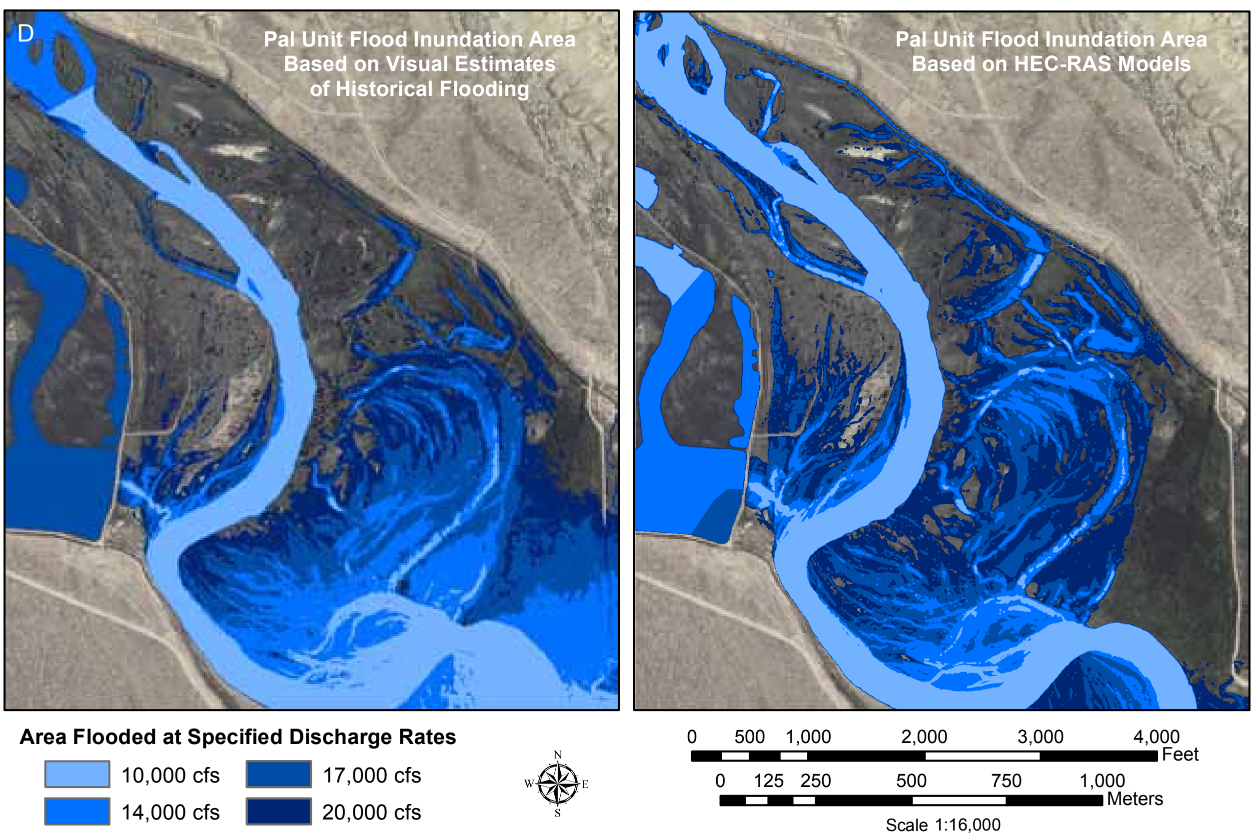


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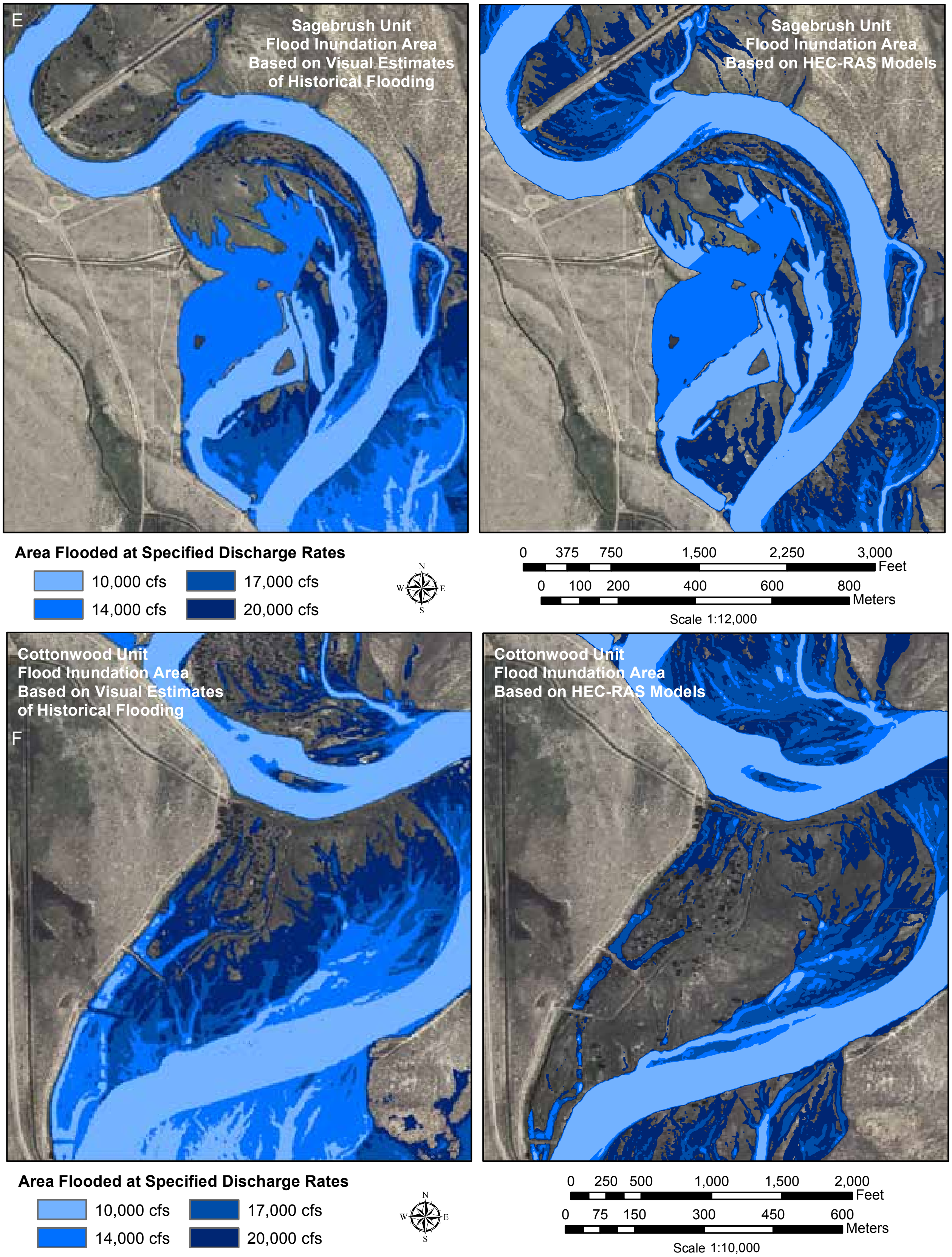
Figure 16, cont'd.



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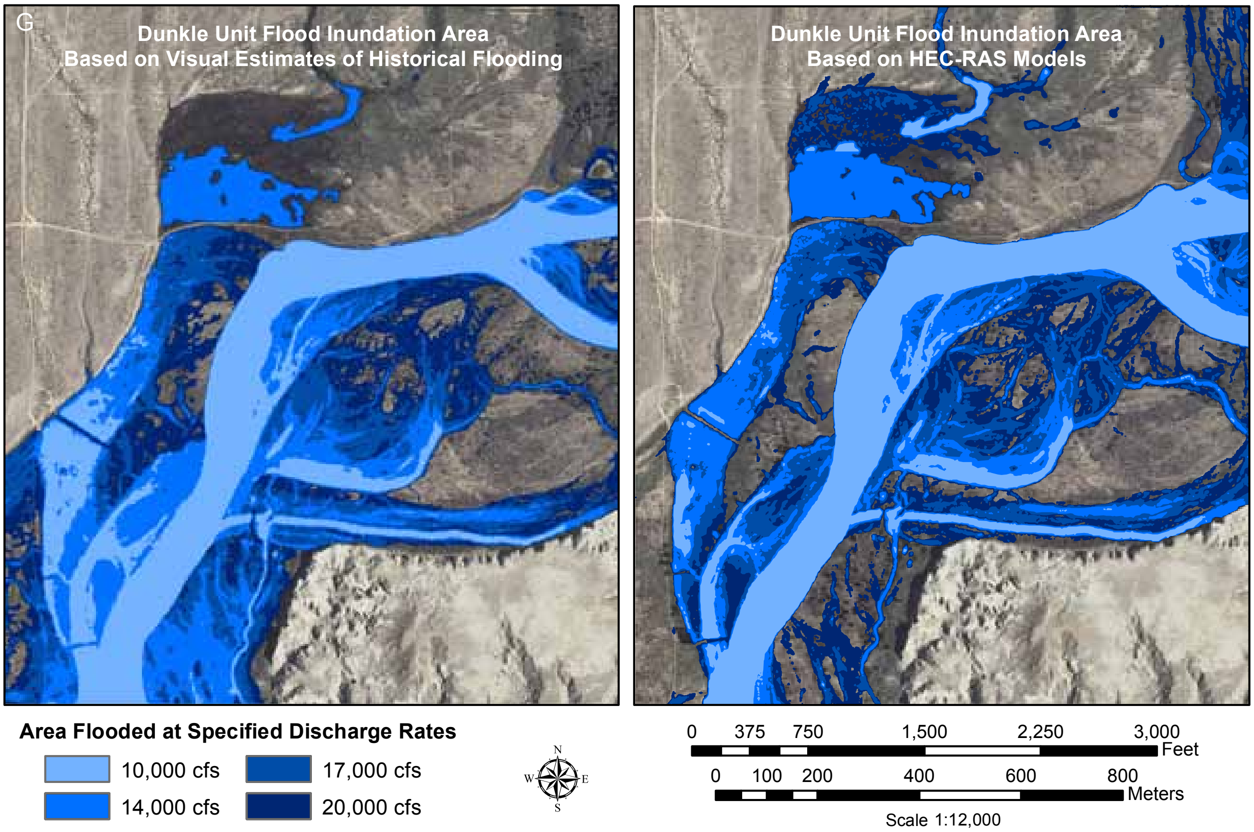

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animal species expected to occur in the various Seedskadee NWR habitats/communities are presented in Appendices B and C.

Areas adjacent to the Green River channel historically contained linear bands of riparian woodland dominated by cottonwood and willow. The historical extent of this riparian woodland is not entirely known, but apparently extended throughout the length of the Green River and Big Sandy River in the vicinity of the refuge as can be seen on the 1965 aerial photographs (Fig. 13). Early explorers commented on corridors and "groves" of trees that probably were dominated by narrowleaf cottonwood, (*Populus angustifolia*) (e.g., see notes in Dorn 1986). Howard Stansbury (1852) an army topographer, crossed the Green River in September 1850 and wrote: "The water was about 3 feet deep at the deepest point. The bottom was about a mile wide and covered with willow thickets and grass and clumps of narrowleaf cottonwood." An early painting of the Green River near Rock Springs, Wyoming by George Caleb Bingham in 1845 also shows a narrow corridor of cottonwood trees along the river bank (Dolin 2010). Tree-ring data indicate that most remnant cottonwood at Seedskadee appear to have been established in the mid-late 1800s (Glass 2002). In addition to narrowleaf cottonwood, riparian woodlands at Seedskadee NWR include coyote willow (*Salix exigua*) and water birch (*Betula occidentalis*) (Appendix B). The mixed shrub and grass understory including Wood's rose (*Rosa woodsii*), gooseberries (*Ribes oxyacanthoides*), basin big sagebrush (*Artemisia tridentata*), red-osier dogwood (*Cornus sericea*), and silver buffaloberry (*Sheperdia argentea*).

The relatively narrow riparian forest corridors at Seedskadee apparently were historically (and currently) present on newly deposited and scoured sand-silt and gravelly soils on natural levee deposits and channel edges/bars (Hansen 1994, Crowl and Goeking 2002). These deposits are most prominent on the inside point bar bends of the Green River channel (Fig. 18). Soils in these areas are well drained, but saturated, for much of the year and usually have some surface flooding each year (Youngblood et al.

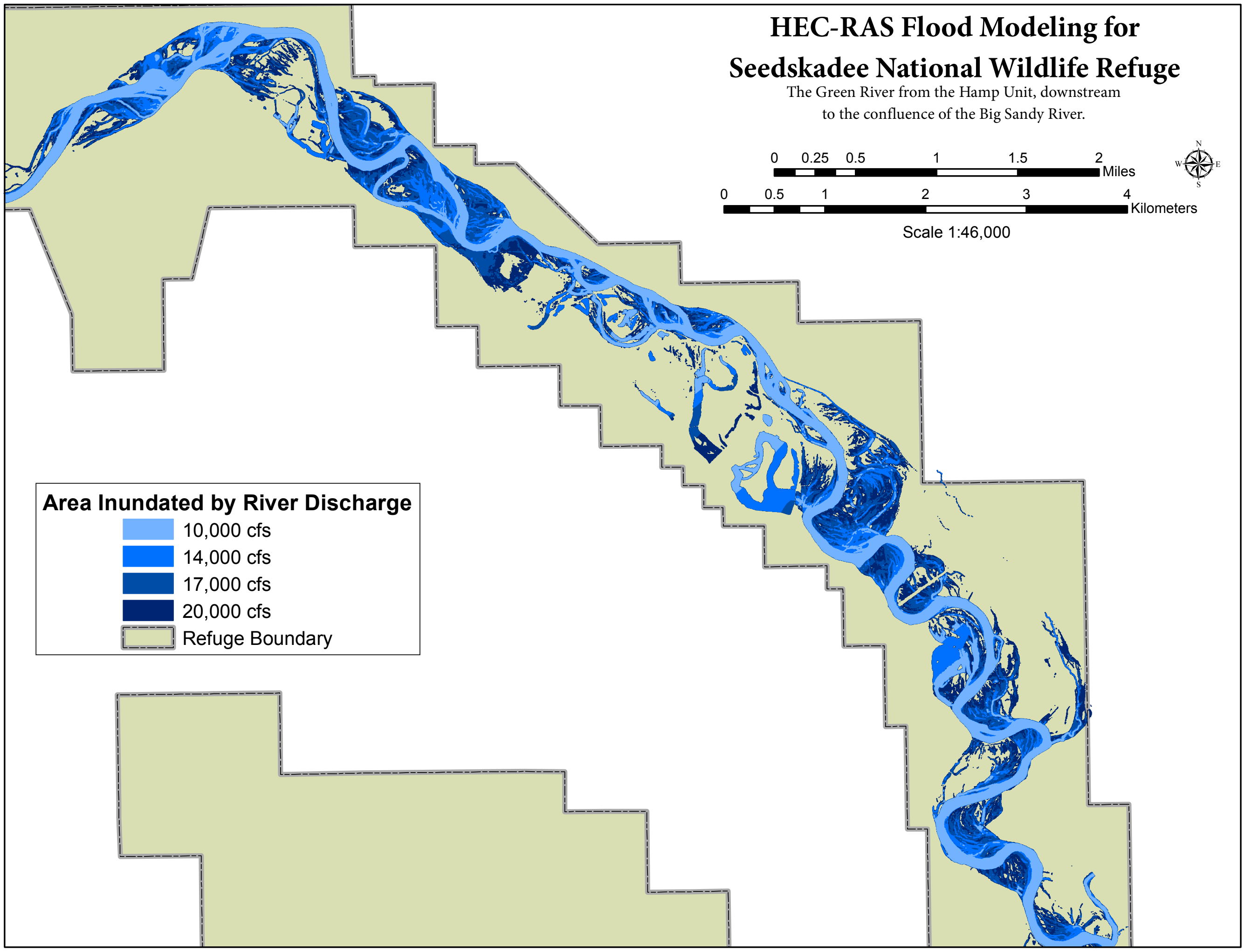

Figure 17. HEC-RAS flood inundation models for Seedskadee National Wildlife Refuge.

1985, Rood and Mahoney 1990, Braatne et al. 1996). Stansbury (1852) noted in 1850 that the Green River " .. streambed here appeared to have been completely filled by the spring rains, overflowing the low grounds and carrying down immense quantities of soil, which has been deposited below, upon the broad flats of Green River." Riparian communities comprise < 1% of the total land area in Wyoming, but have high biomass and diversity of plants and animals and are essential habitats for many species such as Neotropical migrant songbirds (Nicholoff 2003). About 80% of native animal species in Wyoming are dependent on riparian areas for some aspect of their life history (Olson and Gerhart 1982). During high flow events, coarse sediments are deposited on point bar surfaces on inside bends of river channels, and concurrent scouring of channel banks on outside bend areas occurs and exposes underlying sand and gravels (e.g., Heitmeyer and Fredrickson 2005). This periodic changing and exposure of sediments provides new substrates that allow cottonwood seeds to set and germinate. Regular flooding and high water levels in river channels also replenishes, raises, and sustains groundwater levels required by cottonwood seedlings to survive (Cooper et al. 1999, Auble et al. 1997, Auble and Scott 1998, Glass 2002). New sediments also provide ideal soil surfaces for germination of shrubs and some perennial forbs, grasses, and herbaceous plants.

Meander scrolls, high flow channels, and depressions in the Green River floodplain historically contained wetland vegetation ranging from wet grassland in ephemerally flooded areas, sedge-rush and "moist-soil" wetland herbaceous communities in seasonally flooded areas, and small areas of persistent emergent vegetation in deeper depressions where surface water ponded for much of the spring and summer in most years (see e.g., Cronquist et al. 1972).

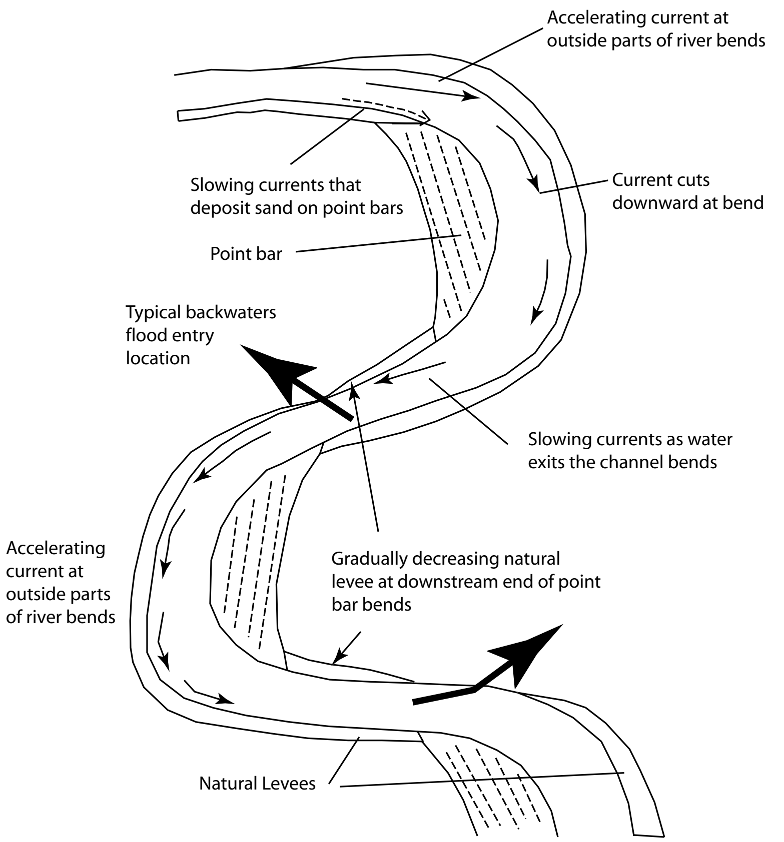

Figure 18. Schematic of typical geomorphic surfaces, river flows, flood entry location and cottonwood stands on the Green River (modified from Heitmeyer and Fredrickson 2005).

These wetland areas typically have clay or silt-clay veneer soils over varied alluvial deposits. Annual and inter-annual flooding of these wetlands was mostly driven by annually rising water levels of the Green River in spring and early summer that caused at least some backwater and overbank flooding of floodplain depressions. As previously described, Green River discharges of about 8,000 to 10,000 cfs occurred in most years and provided at least brief inundation of low elevation swales and depressions from river backwaters (see Fig. 16). Larger flood events that flooded more extensive areas of the floodplain also were relatively common in spring and recharged deeper depressions and shallowly inundated higher floodplain areas. LIDAR topography maps (Figs. 5,6) suggest that relatively few large depressions occurred in the Green River floodplain at Seedskadee NWR. Depressions that existed were mainly relict channels cutoff to form narrow "oxbows." These deeper water areas likely had more permanent water regimes that were recharged regularly by Green River flood water. As temperatures rose and high evapotranspiration rates occurred during summer, the deeper depressions dried on the edges, and perhaps completely dried in low precipitation/flood event years. The semi-permanent water regimes caused by this annual drying dynamic provided habitats for submergent aquatic plants such as coontail (*Ceratophyllum demersum*), naiads (*Najas* sp.), pondweeds (*Potamogeton* sp.), and algae (van der Valk 1989, Hansen et al. 1995, Appendix B). Seasonally flooded margins of floodplain depressions and deeper swales contain mostly non-persistent wetland plants such as arrowhead (*Sagittaria latifolia*), sedges (*Carex* sp.), and rushes (*Juncus* sp.).

Ephemerally flooded areas in the Green River floodplain were inundated for short periods in spring and early summer from onsite precipitation, runoff from adjacent uplands, and flood events. Flooding of these areas was predominantly a "sheetwater flow" type where shallow water flowed across floodplain "flats" and did not originate from a more confined drainage or water flow path. This ephemeral flooding supported wet meadow vegetation species that are tolerant to moist soils such as grasses, sedges, rushes, and some forbs (e.g., Cronquist et al. 1972). Wet meadows at Seedskadee were less extensive than in some other western Intermountain river valleys (e.g., Heitmeyer et al. 2010b), because of the higher river rate-of-fall gradient, narrow floodplain corridor, marked topography caused by frequent river meanders and high flow channels, and relatively abrupt rise in elevation on the edges of the floodplain. Consequently, wet meadow habitats often were relatively narrow bands of slightly higher elevation grass/sedge/rush communities between meander scrolls, swales, and depressions. Seasonal drying and saline soils caused many meadow areas to be at least slightly to moderately saline. Common species in these meadows included western wheat grass (*Pascopyrun smithii*), saltgrass (*Distichlis spicata*), basin wildrye (*Leymus cinereus*), alkali sacaton (*Sporobolus airoides*), and alkali cordgrass (*Spartina gracilis*) (Appendix B).

Upland areas at Seedskadee and the surrounding area in southwest Wyoming and eastern Idaho, including higher elevation edges of the floodplain and terraces, historically were dominated by

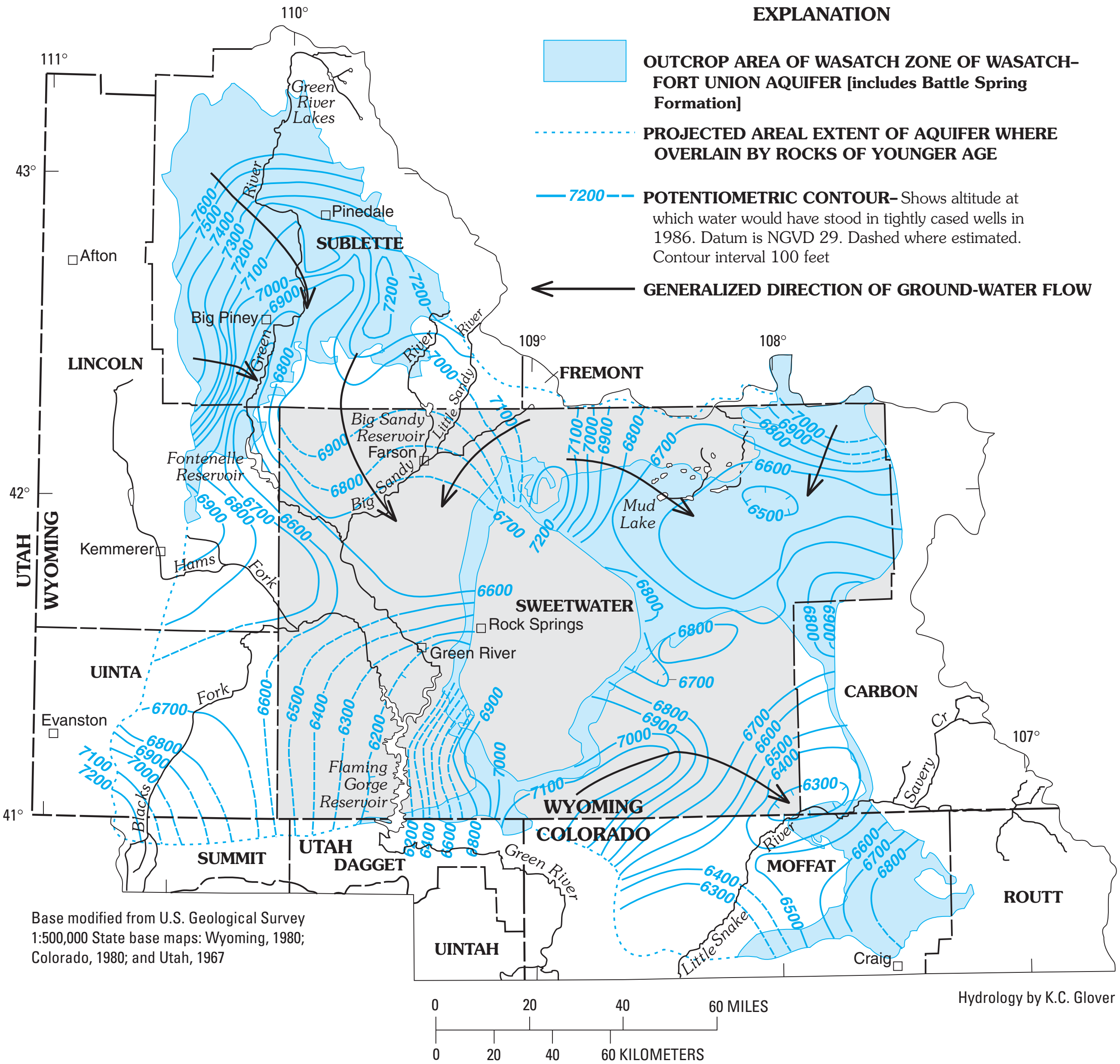

Figure 19. Potentiometric surface and inferred groundwater flow paths for the Wasatch Zone of the Wasatch-Fort Union aquifer, Sweetwater County, Wyoming, 1986 (from Naftz 1996).

sagebrush steppe communities (Cronquist et al. 1972, Hironaka et al. 1983, West 1988, Thompson and Pastor 1995). Soils under this community typically are sandy loams and depth of soil moisture sets limits of specific plant distribution. Big sagebrush (*Artemisia tridentata*) currently is the dominant plant species in sage-steppe communities, but may have been co-dominant with several perennial bunchgrass species under Presettlement conditions (West 1988). The sagebrush steppe community is the largest of the North American semi-desert vegetation types and its floristic diversity is moderate. Shrub layers are typically 0.5-1.0 meter high and cover from 10-80% of a site depending on the site and its succession status. Herbaceous forms are hemicryptophyte (Daubenmire 1970), although the presence of therophytes has increased markedly with disturbance (West 1983). Perennial grasses associated with this community include basin wildrye, wheat grasses, and *Stipa* sp. Pristine sagebrush steppe evolved with

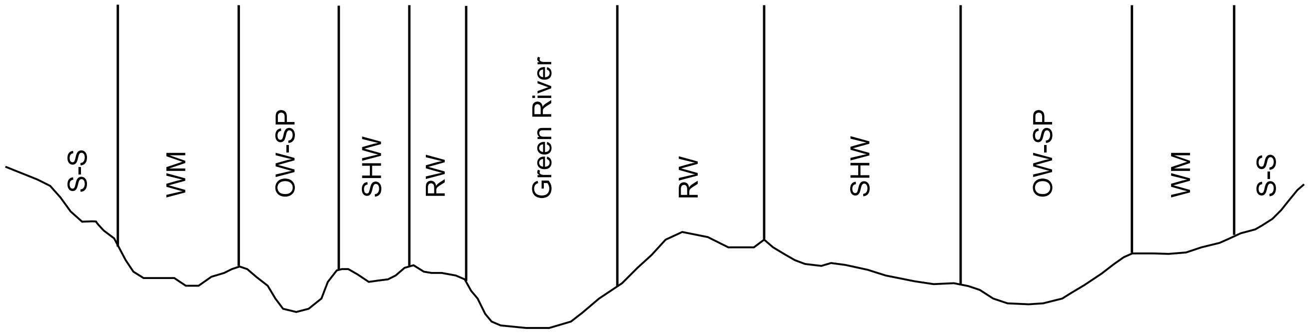

Figure 20. Cross-section of vegetation communities on Seedskadee National Wildlife Refuge.

Table 8. Hydrogeomorphic (HGM) matrix of historical distribution of major vegetation communities/habitat types on Seedskadee National Wildlife Refuge in relationship to geomorphic surface, soils, and hydrological regime. Relationships were determined from land cover maps prepared for the Government Land Office survey notes taken in the early 1800s, historic maps and photographs, U.S. Department of Agriculture soil maps, surficial geomorphology maps (Case et al. 1998), climate and hydrology data for the Green River floodplain; and various naturalist/botanical accounts and literature.

Habitat Type	Geomorphic Surface	Soil type	Flood Frequency[a]
Riverine	Active river channel	Gravel, sand	P
Riparian woodland cottonwood	Natural levee, Point bar ridges	Sandy, silt	A-SFE
Seasonal short emergent wetland vegetation	Floodplain swales	silt loam	A-SF
Open-water persistent tall emergent wetland	Deeper floodplain depressions	silt clay	A-PSMF
Wet meadow grassland	Higher floodplain flats	silt loam, some saline soils	I-TF
Mesic Uplands	Alluvial fans, High floodplain flats	sandy silt loam	R
Dry Uplands Sagebrush steppe	Alluvial fans, Upland terraces	well-drained sandy loam	R

[a] P = Permanently flooded
A-SFE = annually flooded for seasonal periods with extended soil saturation;
A-PSMF = annually flooded with permanent or semipermanent water regimes;
A-SF = annually flooded with short duration seasonal flooding in most years;
I-TP = intermittently temporarily flooded, flooding may not occur every year;
R = rarely if ever flooded, but with seasonal surface sheetflow runoff or groundwater infiltration.

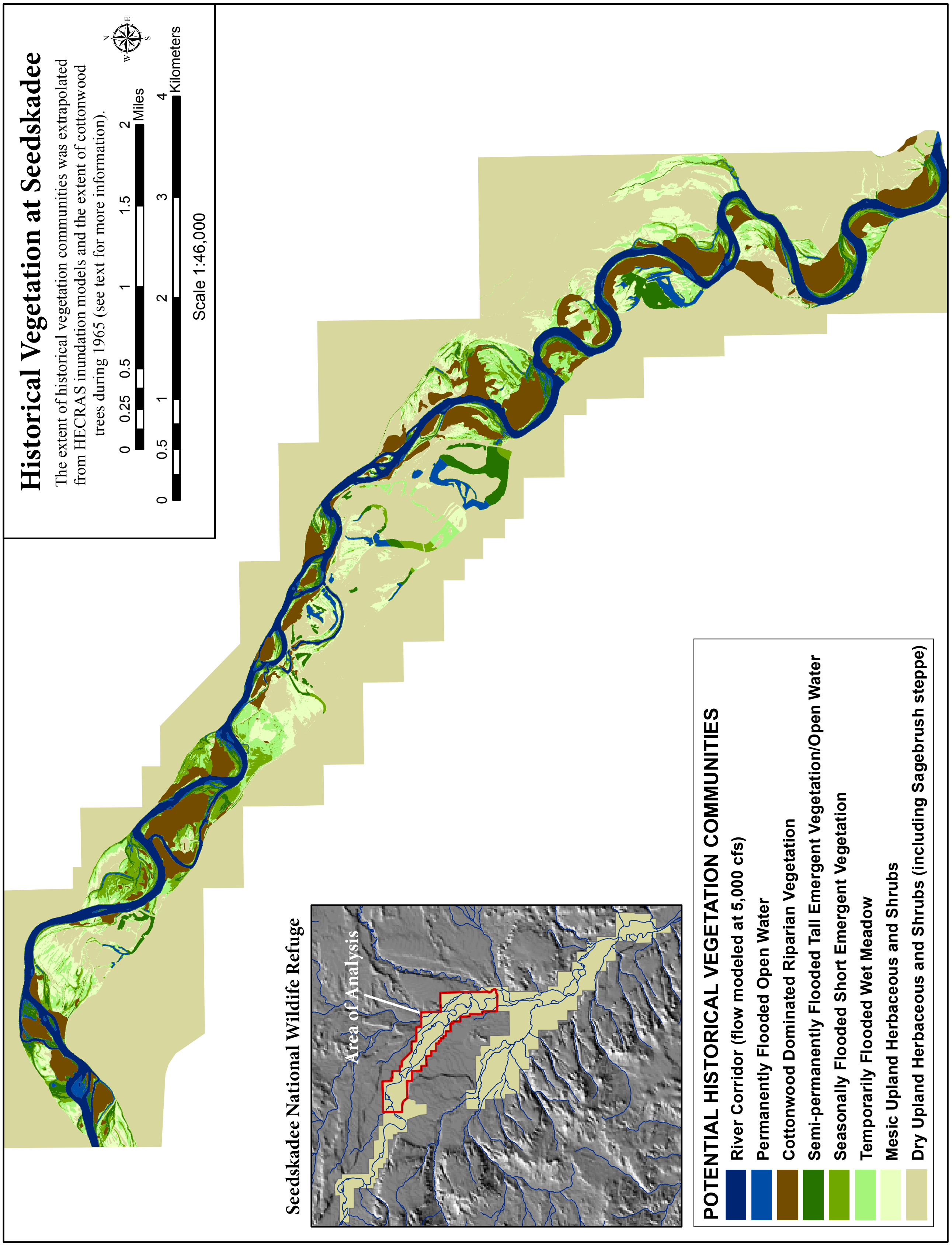

Figure 21. Map of potential historic distribution and types of vegetation communities on Seedskadee National Wildlife Refuge modeled from information in Table 8, HEC-RAS flood inundation maps (Fig. 17), and historical extent of cottonwood seen on old aerial photographs.

large browsers such as antelope, mule deer, and bison (Martin 1970). Fires historically were relatively infrequent in sagebrush steppe communities (Young et al. 1977, West 1988). Presettlement sagebrush steppe was only weakly stable; brush foliage has chemical defenses against herbivory, whereas grasses were highly palatable and native bunchgrasses have high mortality when grazed heavily in spring (Stoddart 1946). They also rarely produce good seed crops (Young et al. 1977). Consequently, heavy grazing from cattle and sheep has greatly altered most native sagebrush steppe areas, including those at Seedskadee NWR, and changes have been further exacerbated by introduction of aggressive annual grasses and weeds such as cheatgrass (*Bromus tectorum*).

A hydrogeomorphic matrix of relationships of the above major plant communities to geomorphic surface, soils, topography, and hydrology was developed to map the potential distribution of Presettlement communities at Seedskadee NWR (Table 8). Historical vegetation communities were estimated based on the extent of cottonwood trees shown in 1965 photographs, HEC-RAS inundation maps, and the flood frequency of varied discharge events (Fig. 21). Generally, communities are arrayed as "bands" or "zones" from the Green River to the uplands on the edges of the floodplain and were strongly related to topography and hydrology. The edges of the Green River channel, including low elevation natural levees and inside river bend point bars contained riparian woodlands. Relict river meander channels, swales, and depressions included relatively small areas of persistent tall emergent vegetation and open water with submerged aquatic vegetation in deeper areas that were semipermanently flooded and sedge-rush communities in seasonally flooded sites. Intervening, slightly higher elevation areas in floodplains contained wet meadow communities that were temporarily flooded by sheetwater flows. Flooding in these areas may be intermittent and not occur every year. Because the Green River is a gaining system influenced by groundwater, an area of mesic grassland/shrubland likely occurred between wet meadow and drier upland habitats. Higher elevation edges of the floodplain, alluvial fans, and upland terraces were dominated by sagebrush steppe communities.

Diverse animal communities historically were present in the various habitat types at Seedskadee NWR. Riparian woodland was used by large numbers animal species including Neotropical migrant birds such as rufous hummingbird, Wilson's warbler, yellow warbler and Bullock's oriole. This habitat also provides important resources to many birds of prey, herons, and mammals including moose, mule deer, beaver, porcupine, and bats (Appendix C). Many reptiles, especially lizards and snakes, also are present in this habitat. Wetland habitats present in the Green River floodplain attracted diverse waterbirds in the otherwise dry sagebrush steppe environment of southwestern Wyoming. Some species such as trumpeter swan, ruddy duck, and cinnamon teal nested and raised broods near the more permanently flooded wetlands, at least during wet years when the Green River had higher flood flow discharges. Other waterbirds used the site mainly during migration, especially in spring; these included American avocets, long-billed dowitcher, several sandpiper species, white-faced ibis, pied-billed grebes, sora, marsh wrens, and yellow-headed blackbirds. Mammals and amphibians also frequented wetland areas. Sagebrush uplands are used by pronghorn, mule deer, greater sage grouse, small mammals, sage sparrow, sage thrasher, Brewer's sparrow, ferruginous hawk, and pygmy rabbit. Several native fish species historically were present in the Green River in the Seedskadee NWR region including cutthroat trout, Colorado pikeminnow, razorback sucker, Utah chub, roundtail chub, humpback chub, bonytail chub, and Bonneville redside shiner (Appendix C). These fish species used both channel and backwater aquatic habitats and periodic flooding of floodplains provides sites for foraging adults and entrainment of larval and juvenile fishes (Wintzer 2008).

Adonia Henry

CHANGES TO THE SEEDSKADEE ECOSYSTEM

This study obtained information on contemporary: 1) physical features, 2) land use and management, 3) hydrology, 4) vegetation communities, and 5) fish and wildlife populations of Seedskadee NWR. These data chronicle the history of land and ecosystem changes at and near the refuge from the Presettlement period and provide perspective on when, how, and why alterations have occurred to ecological processes in the NWR and surrounding lands. Data on chronological changes in physical features and land use/management of the region are most available and complete (e.g., from NWR annual narratives, USDA data and records, sequential aerial photographs, hydrology data from the Green River, etc.) while data documenting changes in fish and wildlife populations generally are limited.

SETTLEMENT AND EARLY LAND USE CHANGES

Native people apparently first occupied southwestern Wyoming 10,000 to 12,000 years before the present (BP) (Frison 1978, Miller and Kornfeld 1966). These early people were small groups of hunter-gatherers and had a highly mobile lifestyle that coincided with seasonal availability of resources; they were highly dependent on big game hunting. Native people continued to occupy southwest Wyoming thereafter, but populations apparently were relatively small with localized and often seasonal settlements. Many of these camp sites and population centers were along the Green River because of the more predictable availability of water, wildlife, and shelter (Thompson and Pastor 1995). Inhabitants of the area collected wild plants, hunted large and small animals, and created chipped and ground tools. The Archaic Period (8,000 to 2,000 BP) in North America was drier and warmer than in earlier times and large prey (horse, camel, mammoth, bison) became extinct or smaller and native people shifted to hunt smaller animals (Thompson and Pastor 1995). They also probably made greater use of vegetable foods that apparently occurred during this period; summers may have been spent in mountains and winters were spent in foothills and valleys. Early Archaic subsistence centered around pronghorn, rabbits, and other small animals including fish and birds obtained in the Green River Valley.

By about 2,000 BP, human populations in southwest Wyoming increased and apparently many small villages were established; evidence of early agriculture is found along some waterways. The Shoshone people spread into the Seedskadee region around 700 BP. They were a nomadic tribe that traveled widely and created multiple trails between the Green River floodplain and nearby mountains (USFWS 2002). The Protohistoric Period began when the first European trade goods and people reached the area in the early 1800s and ended with the development of the fur trapping and trade period in the mid-1800s. An important impact on Native American cultures at this time was the use and control of horses, which assisted hunting bison and made transportation easier (Thompson and Pastor 1995).

In 1811, a party of fur traders representing John Jacob Astor's Pacific Fur Company was the first documented Europeans to visit the Green River Basin (Dolin 2010). Donald Mackenzie, a member of this party later joined the British Northwest Company and organized trapping brigades throughout the region and explored crossings of the Green River that would later be used by emigrants. Hundreds of thousands of pioneers crossed the Green River on sections of the Oregon and Mormon Trails through what is now Seedskadee NWR (Fig. 22). The Pony

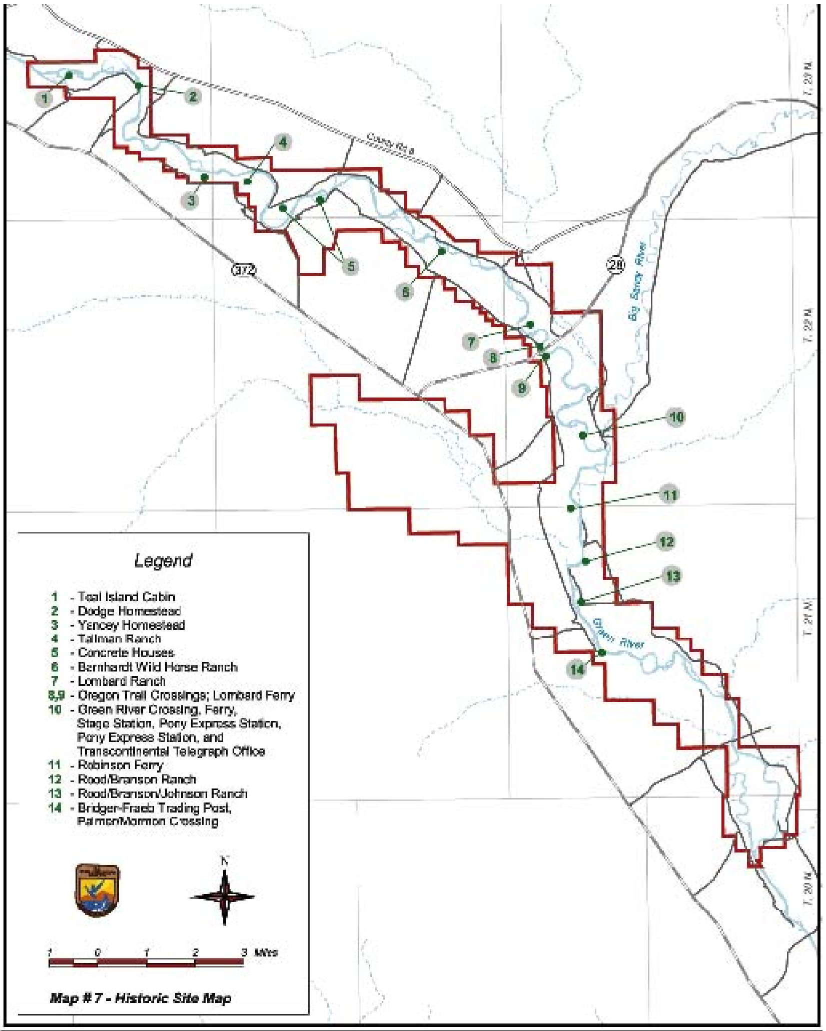

Figure 22. Location of historic sites on Seedskadee National Wildlife Refuge (from USFWS 2002).

Express Trail also crossed the refuge. Jim Bridger and others operated ferries on the Green River in the 1840s and 1850s. The Lombard Ferry, located in the middle part of Seedskadee NWR eventually became the primary crossing of the Green River along the Oregon Trail.

Although the Green River Valley in Wyoming was popular with fur trappers and emigrants, the area offered little attraction for settlers in the mid-1800s because of the remote location, poor soil, and cold climate. Indian uprisings along the Oregon Trail in the 1860s deterred even more settlers. Discovery of gold on South Pass in 1867 stimulated settlement of the area, which was enhanced by the arrival and completion of the Union Pacific Railroad in 1868-69. Soon after, the community of Green River was established. Rock Springs and other towns grew in areas where coal was successfully mined and used to fuel the rail engines. At this time stockmen began to settle the area and by the turn of the century intensive livestock grazing began to degrade and change both riparian and sagebrush steppe communities. Much of the former open range became fenced at this time.

Sweetwater County, that contains Seedskadee NWR, was established in 1865 and is the largest county in Wyoming, covering 10,492 miles^2. The major population centers in the county are Rock Springs and Green River and it currently is the third most populated county in the state. Although the county population is relatively high for Wyoming, much of the county is in public ownership; 68% of the county is public domain administered by the Bureau of Land Management. By the mid-1900s, about 98% of vegetated lands in Sweetwater County were used for livestock grazing. The rich geological formations in the region also led to the development of trona mining and processing, surface coal mining and power generation, oil and gas production, and fertilizer production (Mason and Miller 2005).

CONTEMPORARY LANDSCAPE AND HYDROLOGY CHANGES

The major changes in the Seedskadee NWR ecosystem following more extensive settlement of the region in the late 1800s have been: 1) alterations to distribution, chronology, and abundance of surface and groundwater; 2) alteration of native sagebrush steppe and grassland communities from intensive grazing; 3) reduced and altered riparian woodland; and 4) altered topography including many levees, roads, ditches, borrow areas, and water-control structures on Seedskadee NWR. Additionally, water developments on Seedskadee NWR have impounded many floodplain wetland depressions and created more open water-persistent emergent communities than historically were present.

Agricultural production and extraction of the abundant natural resources in Sweetwater County began to require increasing amounts of water during the mid-1900s (Woolley 1930). Major uses of water in the extraction industry include water used for drilling fluid, secondary recovery of oil, solution mining of trona, and dust control. Water also is used in mine dewatering. Coal bed-methane extraction also required dewatering of coal deposits to release methane gas. The population centers of Green River and Rock Springs obtain water for their use directly from the Green River, while other smaller municipalities in the county rely on groundwater for their public water supply.

Collectively, the attempts to increase agricultural production and supply water for multiple development uses led to the creation of the Seedskadee Project, which was authorized for construction as a part of the 1956 Colorado River Storage Project. The original purpose of the Seedskadee Project was to: 1) divert water from the Green River to deliver irrigation water to 60,720 acres of previously undeveloped desert lands, and 2) develop a wildlife refuge (Seedskadee NWR) to mitigate losses of fish and wildlife habitat (USFWS 2002). Lands proposed for irrigation by the Seedskadee Project were parallel to the Green River and included 51,690 acres of small grain farmlands and 9,030 acres of community pasture. The refuge was to be located along the Green River surrounded by these farm and pasture lands. By 1959, it was determined that a dam and storage reservoir (Fontenelle), as opposed to the originally proposed diversion structure on the Green River, would be required to regulate Green River flows and to deliver irrigation water to farms and the refuge. The 1959 Definite Plan proposed the 18,000-acre Seedskadee NWR with water supplies from irrigation return, Green River, and Fontenelle flows. By the mid-1960s, about 194,000 acres had been withdrawn from public domain, or were acquired by, the Bureau of Reclamation (BOR) for the project and the dam construction and use plans for Fontenelle were modified to include municipal and industrial water storage and use. A stop-order was issued by BOR in 1962 to suspend construction of the originally proposed irrigation delivery canals and infrastructure as it became apparent that the economic feasibility of the original irrigation project was suspect.

Construction of Fontenelle Dam started in 1961 and was completed in 1964. In September 1965, after the reservoir had filled to capacity, water passed through relief cracks in the right abutment, destroyed part of the downstream embankment, and caused high flows and overbank flooding downstream at Seedskadee NWR (Fig. 13). The reservoir was subsequently evacuated and a repair program was completed in 1967. The reservoir was refilled in winter/spring 1967-68 and power generation commenced in May 1968. Total water storage capacity of Fontenelle Reservoir is 345,000 acre-feet that at full pool inundates about 13 miles^2. In 1972, a revised Definite Plan for the Seedskadee Project was prepared that scaled back and phased in acreage that might become irrigated cropland, increased commitments for downstream water for industrial and municipal uses, provided flood control and power generation purposes for Fontenelle Dam, and planed a 34,000 acre-feet annual water supply for Seedskadee NWR. Eventually, the irrigated farm and pasture concept was abandoned as not economically viable for the location and arid climate and because conflicts could arise with successful extraction of underlying and adjacent Green River Basin trona deposits.

Fontenelle Reservoir is managed as part of the extensive Colorado River Reservoir system in accordance with the Colorado River Storage Project Act of 1956, the Colorado River Basin Project Act of 1968, amendments of the Grand Canyon Protection Act of 1992,and the 1944 United States-Mexico Water Treaty. Further, annual operating plans for Fontenelle and other Colorado River Reservoirs are dictated by records of decision (ROD) for the 1996 Glen Canyon Dam ROD, the 1997 Operating Criteria for Glen Canyon Dam, the 1999 Off-stream Storage of Colorado River Water Rule, the 2001 Interim Surplus Guidelines addressing operation of Hoover Dam, the 2006 Flaming Gorge ROD, the 2006 Navajo Dam ROD to implement recommended flows for endangered fish, the 2007 Interim Guidelines for operations of Lake Powell and Lake Mead, and numerous environmental assessments addressing experimental releases from Glen Canyon Dam. Consequently, the BOR, which manages water storage and releases from Fontenelle Reservoir, makes operational decisions annually in response to changing water supply conditions throughout the Colorado River system. The U.S. Congress has charged the Secretary of the Interior with stewardship and responsibility for a wide range of natural, cultural, recreational, and tribal resources within the Colorado River Basin, including the Green River ecosystem at Seedskadee NWR.

Operation of Fontenelle Dam and Reservoir has modified the historical downstream flows of the Green River into and through the Seedskadee NWR and in other downstream Green River floodplain areas. Because the water storage capacity of Fontenelle Reservoir is small relative to inflows from the

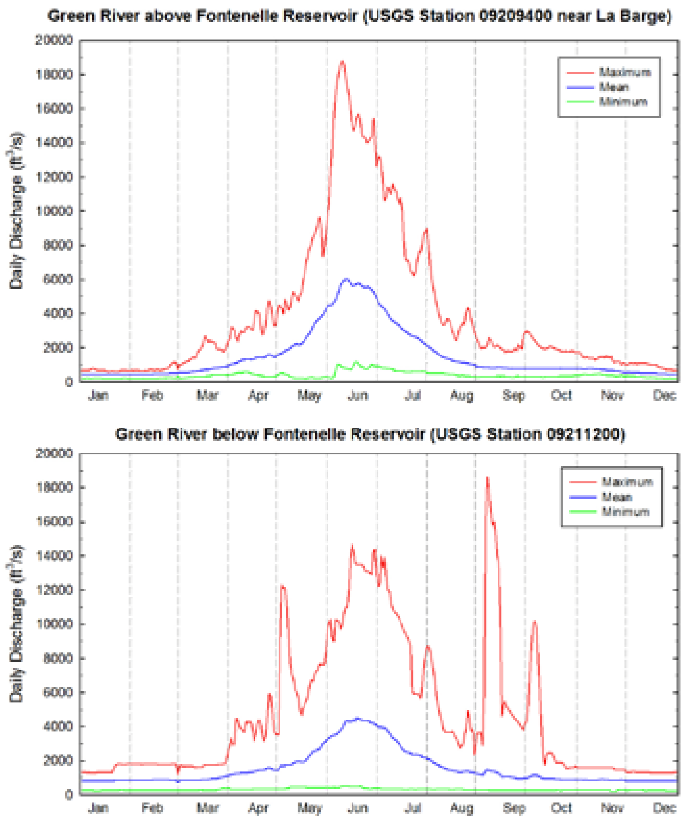

Figure 23. Mean, maximum, and minimum daily discharge (cfs) of the Green River above and below Fontenelle Reservoir, 1964-2009 (data compiled from http://waterdata.usgs.gov/usa/nwis).

Upper Green River Basin, there is limited operational flexibility (USFWS 2002). To accommodate the large spring inflows from snowmelt, reservoir levels are dropped through the winter and early spring to a minimum pool of 93,000 acre-feet by 1 April. Subsequent releases attempt to meet the above mentioned water needs in the Colorado River system. As an example of annual water management, the Fontenelle Reservoir operating plan for 2011 considers the previous year's water supply and downstream flow and storage needs (US BOR 2011). Hydrological conditions in water year 2010 in the Upper Green River Basin were significantly drier than average; inflows to Fontenelle Reservoir from April to July 2010 were only 57% of average because the snow pack conditions in the Upper Green River Basin were only about 65% of average. Further, inflows to Fontenelle Reservoir were below average 9 of the past 10 years and the reservoir did not fill to capacity in water year 2010. In 2010 the reservoir peaked 1.5 feet below spillway level and releases from the reservoir peaked for only 3 days at about 3,050 cfs beginning on 3 July 2010. Releases were then reduced to 1,100 cfs. At the time the 2011 operational plan was written, the BOR estimated that the probable April through July inflow to Fontenelle Reservoir during water year 2011 would be at about 70% of average, which would allow the reservoir to fill and provide slightly higher peak releases in July 2011 compared to July 2010. In actuality, greater late winter and spring snowfall occurred in the Upper Green River Basin in 2011, and peak discharge below Fontenelle Dam was about 8,700 cfs in June 2011.

In general, past operation of Fontenelle Dam has caused water flows in the Green River at Seedskadee NWR to retain a seasonal pattern of increased flows during spring and early summer, but: 1) the spring peak is dampened, 2) occasional high releases, and thus river discharges, occur in fall, and 3) winter flows are somewhat higher than during the pre-reservoir period (Figs. 23,24). Comparing Green River daily discharge during 1964-2009 above Fontenelle Reservoir near La Barge where flows are not affected by Fontenelle Dam to discharges immediately below the dam, the below dam flows had consistently lower June peaks (ca. 14,000 compared to 18,000 cfs), more widely varying discharges, and commonly had a strong September or early October release and high discharge (Fig. 23). From 1952 to 1963, prior to Fontenelle, the mean monthly peak flow in June was 5,466 cfs (Table 5). Post-Fontenelle the mean monthly peak flow in June was 4,518 cfs (Table 9). These flows equated to 325,200 and 268,900 acre-feet of discharge for the same periods, respectively.

Since Fontenelle was constructed, peak flows in the Green River above Fontenelle exceeded 8,000 cfs (a discharge level where at least some minor backwater flooding might occur at Seedskadee NWR) 10 times, but similar discharges of at least 8,000 cfs below the Dam occurred only 3 times (Fig. 24). Since 1966, five flow events above Fontenelle were > 13,000 cfs, while similar flows > 13,000 cfs occurred only three times below the dam (USFWS 2002). From 1971 to 2001, Fontenelle Dam altered natural extremes in seasonal high and low flows, and reduced peak flows in 29 of 38 years (Fig. 25). Long-term data generally indicate that flows in the Green River system have declined from very wet periods in the late 1800s and early 1900s to the present. Discharges at Green River, Wyoming > 20,000 cfs, which would flood most of the Seedskadee NWR floodplain (see earlier Climate and Hydrology section of this report) have not occurred since the 1920s. Flows at the long-term gauge station

Table 9. Monthly and annual streamflow of the Green River after construction of Fontenelle Reservoir 1964-2002 for USGS gauge station #09127000 near Green River, Wyoming (from Mason and Miller 2005).

Month or annual	Water year			Streamflow, in cubic feet per second				Coefficient of variation (unitless)	Percentiles, in cubic feet per second					Mean runoff	
	Begin	End	Total	Maximum	Minimum	Mean	Standard deviation		10th	25th	50th	75th	90th	Acre-feet	Percent of annual
10	1964	2002	39	3,109	279	1,036	497	0.48	510	752	940	1,225	1,413	63,700	5.19
11	1964	2002	39	1,844	281	920	316	.34	484	795	921	1,118	1,261	54,720	4.46
12	1964	2002	39	1,419	272	816	319	.39	408	490	835	1,064	1,210	50,160	4.08
1	1964	2002	39	1,442	266	848	347	.41	367	516	905	1,137	1,257	52,140	4.25
2	1964	2002	39	1,980	267	911	402	.44	380	621	864	1,166	1,340	51,010	4.15
3	1964	2002	39	1,852	350	1,080	418	.39	542	708	1,167	1,365	1,634	66,390	5.41
4	1964	2002	39	3,195	516	1,587	692	.44	782	1,157	1,388	2,007	2,631	94,450	7.69
5	1964	2002	39	5,503	434	2,434	1,395	.57	900	1,298	2,247	3,363	4,480	149,700	12.2
6	1964	2002	39	11,700	414	4,518	2,933	.65	851	2,617	4,151	5,991	8,418	268,900	21.9
7	1964	2002	39	9,416	368	3,310	2,456	.74	798	1,436	2,508	4,820	7,347	203,500	16.6
8	1964	2002	39	3,578	372	1,633	765	.47	611	1,089	1,627	2,100	2,605	100,400	8.18
9	1964	2002	39	7,746	251	1,229	1,140	.93	546	863	1,099	1,261	1,495	73,120	5.95
ANNUAL	1964	2002	39	3,089	576	1,695	657	.39	820	1,204	1,695	2,076	2,454	1,228,000	100

at Green River, Wyoming are affected primarily by the Green River releases at Fontenelle, but also have some contribution from the Big Sandy River. Given this caveat, these flow data from Green River, Wyoming indicate that the frequency and magnitude of Green River flows that would be sufficient to cause at least some overbank and backwater flooding of the Seedskadee NWR floodplain at about 8,000 to 10,000 cfs has been significantly reduced from about once every 2 years to now > 10 years. This reduced early spring and summer flooding has obvious negative consequences of reduced recharge dynamics for floodplain wetlands, drought induced mortality of riparian trees such as cottonwood, and altered nutrient and sediment inputs (Scott et al. 1993, 1999, Mahoney and Rood 1998). In contrast, the operation of Fontenelle Dam has pronounced or exaggerated late summer and early fall discharges compared to historical flows, with potential for occasional flooding, such as occurred in 1970, 1981, 1983, and 1990. This late summer and fall flooding can negatively impact recruitment of riparian and floodplain vegetation by drowning seedlings (Auble et al. 1997).

Comparison of cottonwood stands on aerial photographs from 1965 with 2009 NAIP imagery shows about a

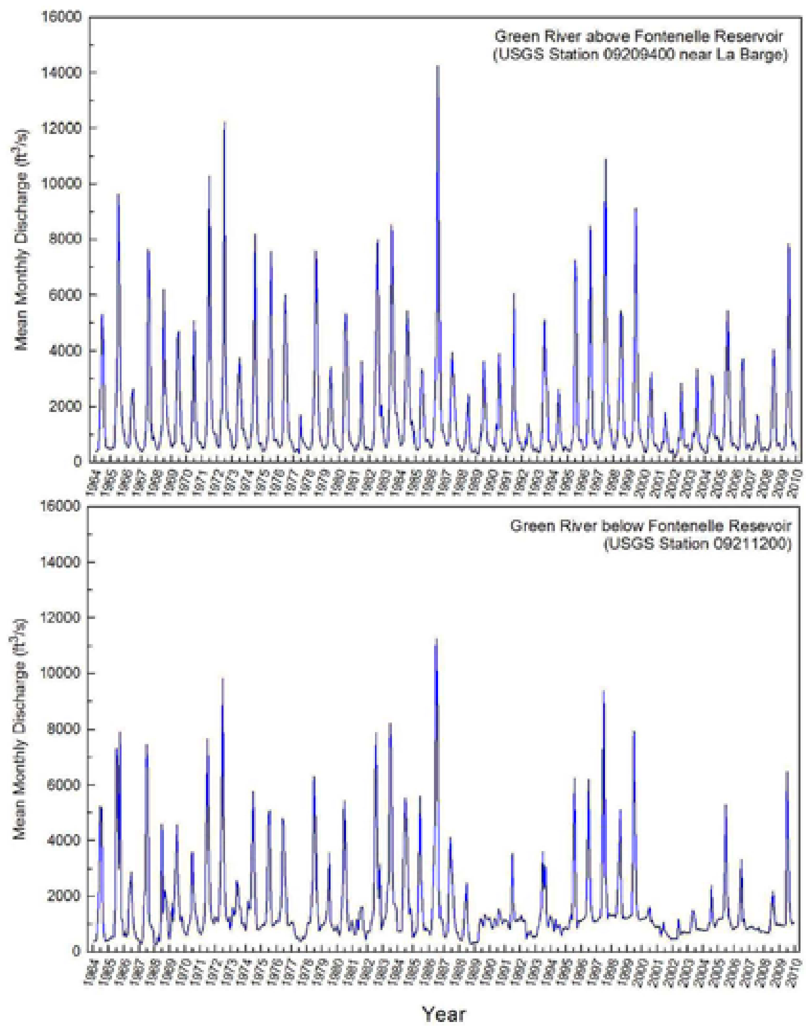

Figure 24. Mean monthly discharge (cfs) of the Green River above and below Fontenelle Reservoir. Long and short marks above year on the x-axis represent 1 January and 30 June, respectively (data compiled from http://waterdata.usgs.gov/usa/nwis).

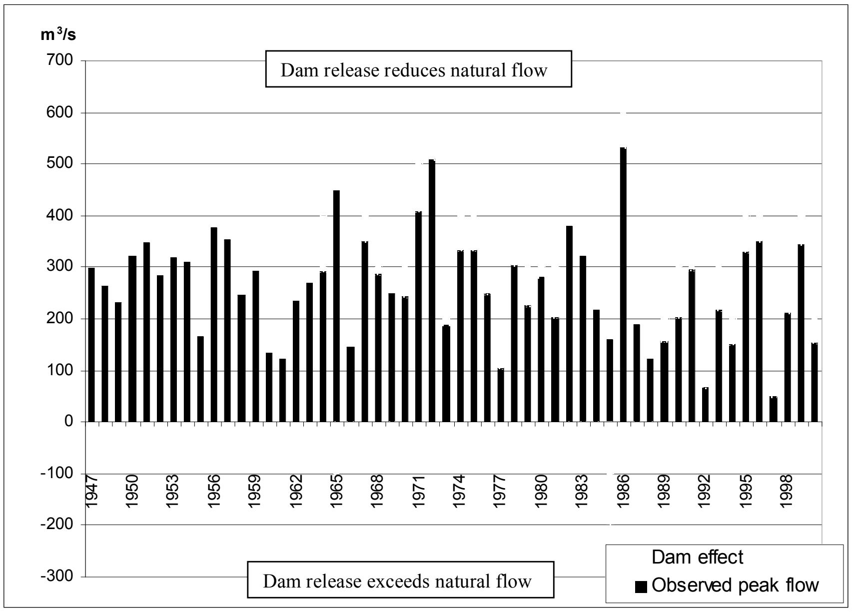

Figure 25. Effects of Fontenelle Dam on peak flows of the Green River 1947-2000. "Dam effect" indicates the difference between inflow and outflow of Fontenelle Reservoir. Negative dam effects indicate that the peak flows below the dam exceeded peak inflows. (from Glass 2002).

60% decrease in area of cottonwood habitats. Habitat mapping based on 1997 color infrared imagery (Fig. 26) also shows a decline in cottonwood areas from the historical extent. Additional analyses of the vegetation radar-return data from the LIDAR flown in 2010 also could be used to provide further information on the current extent of cottonwood and other taller woody and emergent vegetation.

Other realized or potential consequences of Fontenelle Dam to the Seedskadee NWR ecosystem include artificial rapid drops in Green River stage and reduced sediment loads in the river (Glass 2002). Rapid drops in river stage can cause a quick decrease in surface water flooding duration and also a decrease in the groundwater table of floodplains. Rapid declines in, and general lowering of base, groundwater levels in dry summer months have the potential to cause drought stress in riparian cottonwoods as seedling roots become desiccated (Mahoney and Rood 1998). At Seedskadee, relatively rapid decreases in rate-of-fall during summer of > 4 cm/day have become common (Auble et al. 1997). Alteration of alluvial groundwater response to changes in Green River stage at Seedskadee NWR also is apparent (Scott et al. 2008). Reduced sediment loading causes reduced deposition in floodplains and the river channel, which disrupts lateral migration tendencies of the river and causes increased net erosion in the downstream riverbed, often with vertical incision in upstream areas. This incision also has the potential to decrease groundwater levels in floodplains and can "strand" higher elevations, such as natural levees, along the river bank. Evidence for incision of the Green River below Fontenelle Dam is weak, but in contrast, stranding of floodplain "terraces" (point bar ridges and natural levees) which formerly regularly flooded and supported cottonwood recruitment, is apparent (Glass 2002).

ESTABLISHMENT AND MANAGEMENT OF SEEDSKADEE NWR

Seedskadee NWR formally was established in 1965 to partly mitigate the loss of habitat that resulted from construction and subsequent operation of both Fontenelle and Flaming Gorge Reservoirs on the Green River. Acquisition of lands for the refuge began in 1966 and eventually created the 25,970-acre refuge, which had original goals for providing suitable habitat for waterfowl and other waterbirds, along with supporting valuable riverine and riparian habitats. The BOR is responsible for funding land acquisitions and developments to offset loss of wildlife habitats in compliance with Section 8 of the Colorado River Storage Project. Since 1958, the BOR and USFWS have worked cooperatively to mitigate the habitat losses from Fontenelle Reservoir. The original acquisition boundary for Seedskadee NWR was designated in Public Land Order 4834 in 1970 and included 22,112 acres (USFWS 2002). In 1990, the boundary area increased with the purchase of additional lands deemed as "uneconomic remnants." In 1998, additional lands were acquired from BOR withdrawn lands and by 2010, the refuge had expanded to its current acreage. The refuge has water rights that include: 1) irrigation water rights attached to the agricultural lands acquired for the refuge (this water can be used for restoration, enhancement, and management of wetlands); 2) first priority to 5,000 acre-feet of Fontenelle Reservoir storage water under Contract No. 14-06-400-6193; and 3) an allocation of up to

28,000 acre-feet annually, at a rate of 115 cfs, deliverable under BOR Direct Green River Flow Permit (USFWS 2002). Purchase of many tracts of land on the refuge were subject to existing rights-of-way or granted in deeds at the time of purchase and many tracts also contain outstanding reserved subsurface mineral rights. Currently about 2,400 acres of active oil and gas leases occur on the refuge and minerals are privately owned on about 15,000 acres (USFWS 2002).

While the original management purpose and objectives for Seedskadee were to provide habitats for migratory waterbirds, especially waterfowl, overtime the management direction for the refuge has become more holistic (USFWS 2002). For example, the 1987 management plan for the refuge (USFWS 1987) stated objectives as:

1. To develop and maintain wetland habitat (primarily as nesting and brood-rearing habitat for Canada geese and other waterfowl).
2. To preserve habitat conditions for the benefit of native wildlife species thus ensuring wildlife diversity in the area, as well as providing habitat for rare and endangered species which frequent the area.
3. To provide opportunities for interpretation and recreation to the visiting public.

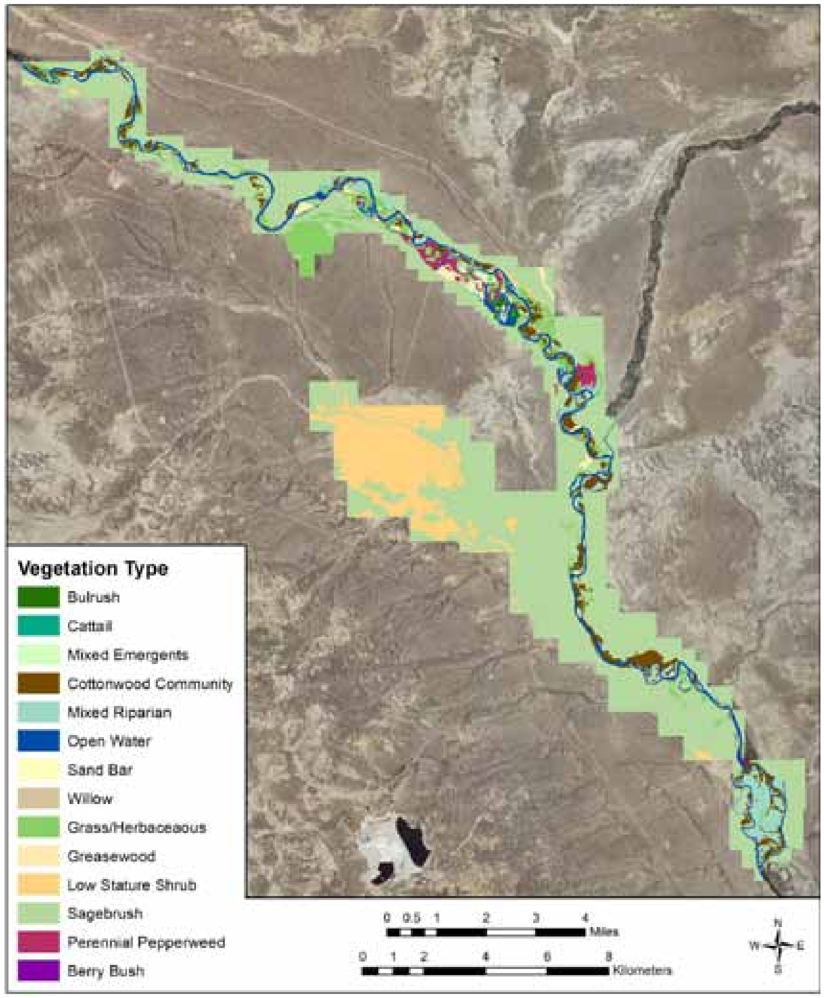

Figure 26. Vegetation communities at Seedskadee National Wildlife Refuge, 1997 (from Berk 1998).

The 2002 CCP for the refuge further broadened the management focus for the refuge with specific goals for wildlife; habitat; and public use, recreation and resource protection. Although the CCP suggested broader ecosystem goals, it maintained specific objectives for key species such as bald eagles, trumpeter swans, whooping cranes, mountain plovers, Ute ladies'-tresses, moose, mule deer, and sage grouse. Further, specific objectives were developed for riparian restoration, management of wetland impoundments, riverine, and sagebrush steppe areas (USFWS 2002). Control of invasive plants also was noted as a management concern and objective. About 20 habitat management areas (units) have been established for the refuge (Fig. 27)

Following establishment of Seedskadee NWR, wetland development activities began on the refuge and have continued to the present (Table 10). The most substantial developments occurred in the 1980s, when the Hamp, Hawley, Lower Hawley, and Dunkle wetland impoundments were rehabilitated or created (Fig. 28). The development of these wetland impoundments included gravity flow diversions from the Green River and a series of ditches, levees, and water-control structures to create the impoundments and to irrigate wet meadow areas. Three key "hard point" rock weir structures built across the Green River channel essentially "dam" the river behind the structure to the top elevation of the rock weir and cause water to flow through a "headgate" into distribution canals that serve the impoundments. Wetland impoundments now total about 1,700 acres and they are subdivided with numerous small levees, ditches, water-control structures, and other infrastructure.

The 55-acre Hamp impoundment is fed by the Hamp No. 1 headgate diversion and water gravity flows into the wetland (Fig. 28). At Green River flows of > 2,000 cfs adequate water exists to maintain the impoundment at full pool. Pool depths range from about 1-5 feet (Fig. 6). The impoundment is subdivided and has 7 water-control structures (mostly drop-board type), however management of individual pools is difficult because they cannot be independently flooded or drained. The Hawley (24 acres), Lower Hawley (147 acres), Sagebrush, and Dunkle (36 acres) impoundments are fed by the Hamp No. 2 headgate diversion point and water gravity flows into the Hawley impoundment first, then into and through the Lower Hawley and Sagebrush impoundments to eventually provide water to the Dunkle impoundment (Fig. 28). At flows > 1,200 cfs, adequate water exists to maintain most of the Hawley impoundment at full pool. At lower discharge levels, water must be rotated between individual pools to maintain adequate head pressure to move water and maintain water levels in the units. Given the "flow through" system of these wetland impoundments, they do not have independent management capability, except for the Hawley impoundment. The Pal management unit contains 73 acres and is supplied by the Superior headgate diversion and the Superior Ditch system. No internal dikes are present in the unit and water flows over low floodplain depressions and into a relict river oxbow. Most of the area functions as a wet meadow and water levels drop in the unit as Green River water levels fall. The Sagebrush Unit (Fig. 28) is a small wetland site located on the west side of the Green River between the Lower Hawley and Dunkle impoundments. Flooding of this unit was accomplished by moving water from the distribution ditch routed to the Dunkle impoundment and management relies on high Green River water flows. In 2004 a dike was built across the Sagebrush unit to subdivide it.

Management of the wetland impoundments and unit areas (excepting Pal Unit) on Seedskadee NWR typically has sought to flood at least some impoundment pools beginning in mid-March after the thaw, and to maintain full pool levels through the fall to provide nesting and brood-rearing

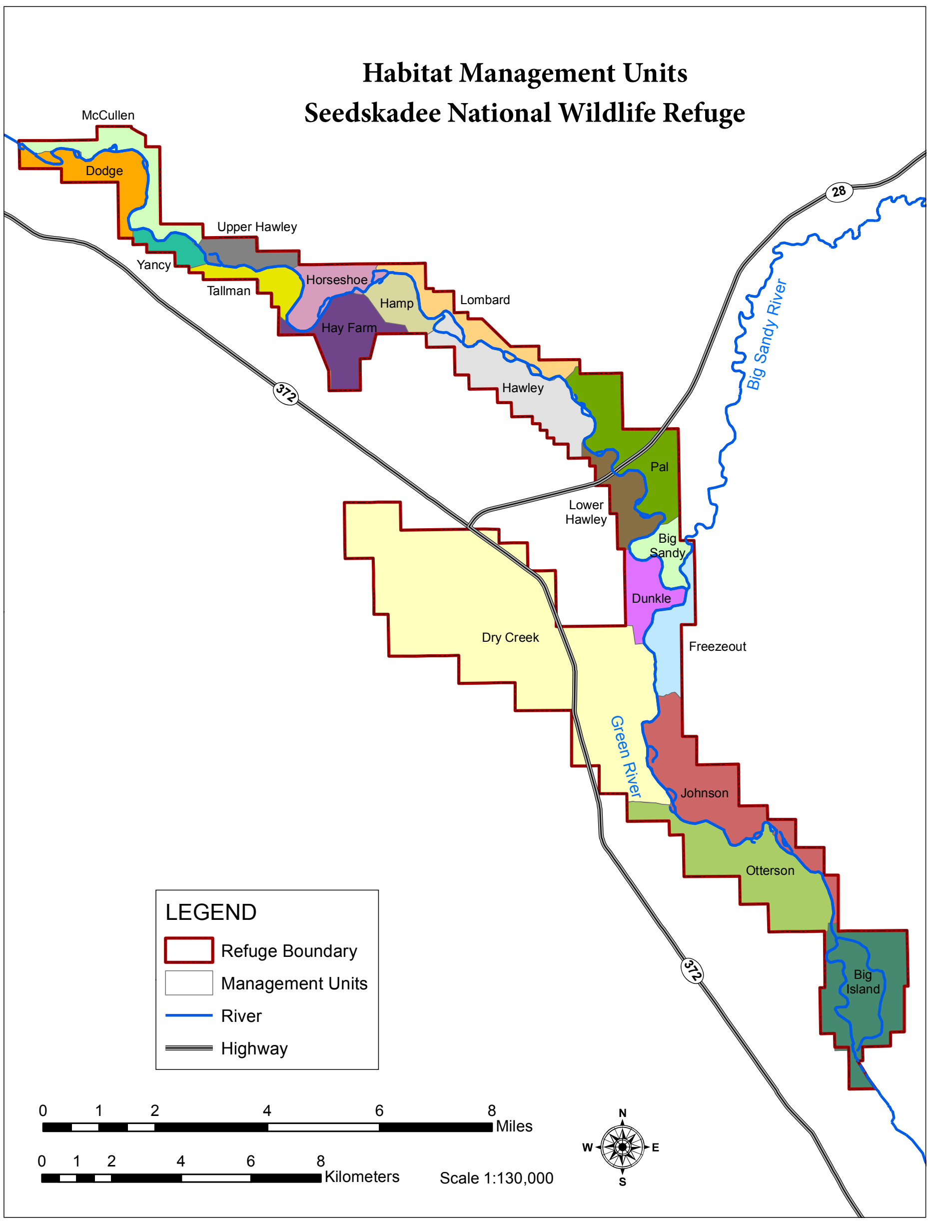

Figure 27. Habitat management units on Seedskadee National Wildlife Refuge (from USFWS 2002).

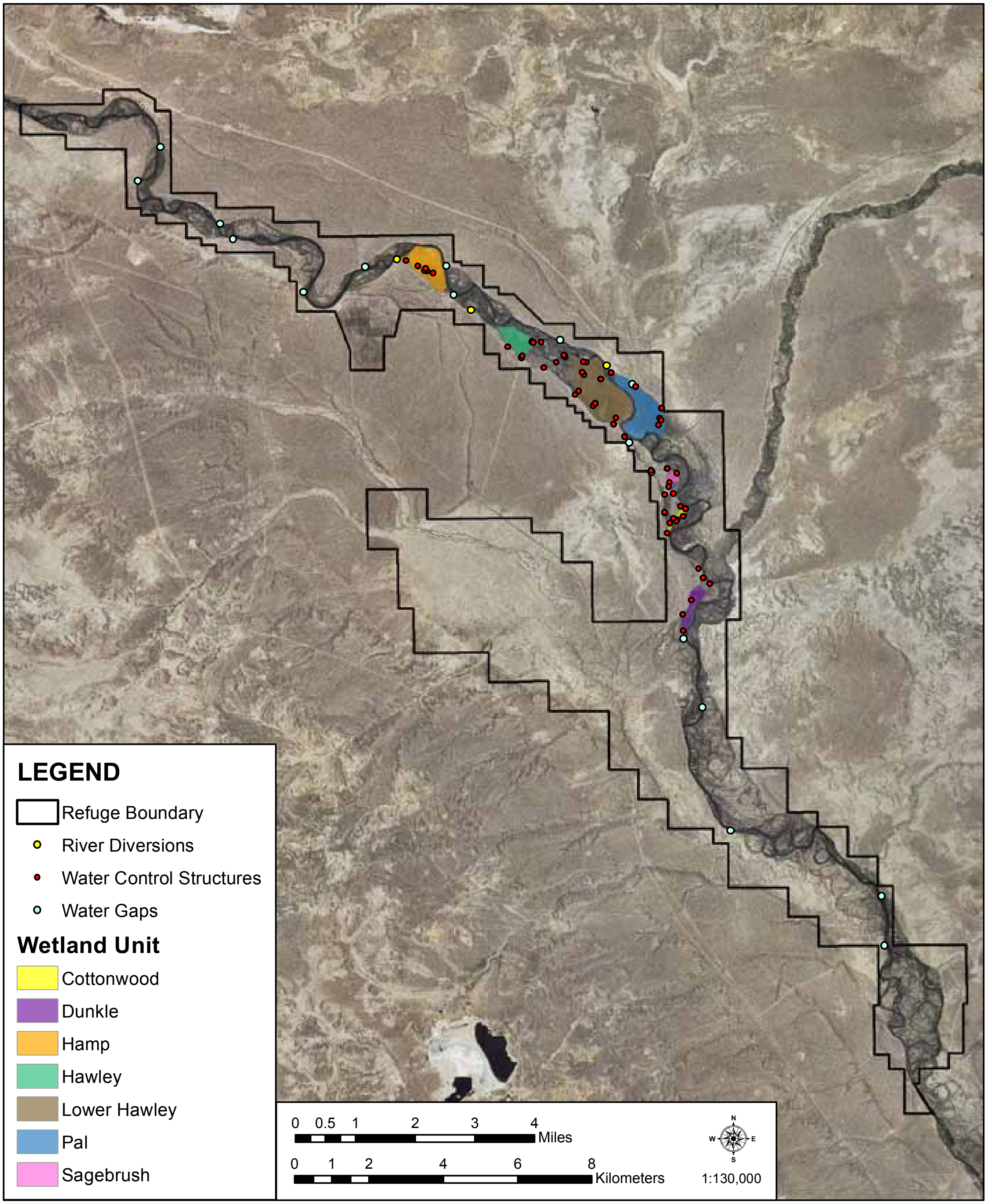

Figure 28. Location of water-control structures and points of diversion for wetland impoundments on Seedskadee National Wildlife Refuge.

Table 10. Chronology of wetland developments on Seedskadee National Wildlife Refuge (compiled from unpublished USFWS annual narratives).

Year	Wetland Development Activities
1956	Refuge authorized by the Colorado River Storage Project.
1961-64	Fontenelle Dam built on the Green River.
1965	Refuge established through a Memorandum of Understanding between U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service.
	Existing irrigation ditches and diversions used as a water supply for wetland management.
1967	Rehabilitated two dikes and one headgate structure in the Hawley Tract.
1968	Completed repairs at Fontenelle Dam.
1968-72	Improved existing infrastructure in the Hawley Unit and Units 6, 8, 9, 10, and 11. Improvements included replacing culverts with concrete water control structures, raising and widening dikes, installing new water control structures and turnouts, and constructing pump ramps, new small dikes, ditches and plugs for better water spreading.
1977	Hawley gravity flow canal and center dike rehabilitated to replace washouts.
1978	Blockhouse Unit constructed.
1980-82	Rehabilitated Hawley Unit dike roads and No. 2 dike, cleaned and rehabilitated Hamp No. 2 ditch, and replaced and reset culverts in Hamp No. 1 ditch.
1982	Installed new headgate and diversion structure.
	Riprapped 800 feet of Refuge channels.
	Riprapped 1400 feet along the Green River.
	Stop log structure with new screw gate built at Hamp No. 2 ditch and Hamp No. 2 lateral junction.
	Low dike rebuilt and lengthened to increase surface area of marsh
1984	Wetland restoration actions completed at Hamp and Hawley Units, including cleaning and constructing 30,624 linear feet of ditch, constructing 9,637 linear feet of dikes, installing 95 control structures and four reinforced concrete pipes, and placing 935 cubic yards of filter blanket and 1,879 cubic yards of riprap.
	Shoreline protection work along 2,350 linear feet of the Green River included clearing and grubbing, removing old car bodies, and placing 3,390 cubic yards of filter blanket and 6,770 cubic yards of riprap along the river bank.
	Roadway for Highway 28 cleared and construction of new bridge started.
1985-86	Wetland restoration actions completed in Lower Hawley and Dunkle Units increasing wetland area to 100 acres. All 6 dikes in the Dunkle and Lower Hawley Units accepted at 1-1.5 feet below specifications.
	Dug Dunkle Ditch as an extension of the Hamp No. 2 ditch.
1987	New CMP flashboard riser water control structure installed in Hamp No. 2 ditch just below inlet of Hawley Pool No. 1.
	Raised level of Dunkle and Lower Hawley dikes to specifications.
1988	Repairs made to Fontenelle Dam.

Table 10 cont'd. Chronology of wetland developments on Seedskadee National Wildlife Refuge (compiled from unpublished USFWS annual narratives).

	Raised and/or widened sections of the Hamp No. 2 ditch road.
	Widened and resurfaced dikes in the Hawley Unit along pools 1, 4, and 6.
	Raised Hay Farm Pond 2 dike 3 feet to more than double effective pool height and installed CMP flash-board riser control structure.
1989	Constructed two new wetland basins in the Hawley Unit with six nesting islands, five dikes, and two flashboard riser control structures.
1990	Created Hay Farm pool 3 by constructing a dam in the drainage below Hay Farm pool 2.
1991	Rock sills placed immediately downstream of the intake of Hamp No. 1 ditch to allow complete filling of Hamp Unit and to restore flow to an old river oxbow on the opposite side of the bank.
	Filter blanket and riprap installed to dissipate energy from the sills.
	Fish walls and fish habitat structures installed to provide habitat for trout and salmon.
1992	Gravel constriction at mouth of Green River at Deer Island Slough cleared several times and a large rock in the river was moved to form a curving jetty resulting in a higher volume of water in the Hamp No. 2 ditch.
1994	Thirteen rock sills constructed on the Big Sandy River to provide cover for juvenile trout and deep water habitat for larger fish.
	Rock sill constructed across the Green River on the McCullen Unit to provide critical winter juvenile trout habitat and to restore flow to an old oxbow to improve riparian vegetation.
1996	Rock placed at three water lanes.
	Twelve additional rock sills constructed on the Big Sandy River near Bone Draw.
1999	Pipeline and water control structure installed in Hamp No. 2 ditch south of the Hawley Unit.
	Small rock diversion structure and four small rock groins constructed in small oxbow near Lower Dodge Bottoms.
2000	Rehabilitated Superior Ditch by replacing 900 feet rock jetty with buried 48-inch pipe, replacing the intake structure, cleaning silt and debris along 4,200 feet of existing ditch, constructing 2,700 feet of new ditch, installing 14 water control structures, and constructing 5,200 feet of service road on the east and west side of ditch berm.
2004	Removed nesting islands from Sagebrush and Cottonwood Units
	Constructed a dike across the Sagebrush Unit to provide better water management.
	Installed two new water control structures along Hamp No. 2 ditch.
	Completed road improvements to the Superior Ditch.
2005	Installed five drop board structures and one culvert in the Cottonwood Units eastern ditch system.
	Installed control structure in Hamp ditch.
	Made emergency repairs to the Hamp No. 2 gabion located on Deer Island channel; plans initiated for replacement of rock gabion with radial gated control structure.
	Installed one water control structure (C8) and replaced four structures (C4, C6, C7 and Hamp 2).
2007	Repaired two control structures at the Pal Unit.

habitat for waterfowl, especially trumpeter swans, and for spring and fall migration habitat. The Pal wet meadow area generally is flooded for 2-3 weeks in spring to provide foraging habitat for shorebirds, cranes, and waterfowl. A consequence of the annual semipermanent to permanent flooding in most impoundments has been an increase in the coverage of persistent emergent vegetation, primarily cattail, in impoundments over time (Berk 1998, Figs. 26,29). Attempts have been made to control the extensive, sometimes monotypic, stands of cattail using drawdowns, prescribed burning, and tillage with a goal of maintaining about 50% of impoundment pools in open water habitat. In the 1980s, many islands also were built in the wetland pools, although some were removed during the mid-2000s. Other past management for nesting waterfowl included construction of predator fences and planting dense nesting cover plots. Active predator control to enhance nesting success of ground-nesting birds also was conducted at times in the past.

Invasive plant species such as perennial pepperweed (*Lepidium latifolium*) and Canada thistle (*Cirsium arvense*) have expanded greatly in many floodplain and some upland areas (Fig. 26). Biological, mechanical, and chemical controls have been used to manage these invasive plants. Most upland sagebrush steppe communities currently are fenced and not grazed, although at times in the past grazing was allowed on some parts of the refuge. For example, the large Dry Creek Unit (Fig. 27) has been fenced and free of grazing by domestic livestock since 1983. Seventeen fenced livestock water access lanes (water gaps) are present on the refuge to allow livestock (from off-refuge grazing lands) access to the water in the Green River (Fig. 28). The historic intense livestock grazing in upland areas plus occasional fire and ground disturbance has altered the community structure of upland sagebrush habitats with the introduction of nonnative annual weeds including halogeton (*Halogeton glomeratus*), Russian knapweed (*Acroptilon repens*), tansy mustard (*Descurainia sophia*), clasping and perennial pepperweed, Canada thistle, and cheatgrass (*Bromus tectorum*) (Chaney et al. 1990, Fig. 26). By 1990, perennial pepperweed covered over 1,200 acres of the refuge (USFWS, unpublished annual narrative for Seedskadee NWR). Further, the basin big sagebrush component of the community has declined (USFWS 2002).

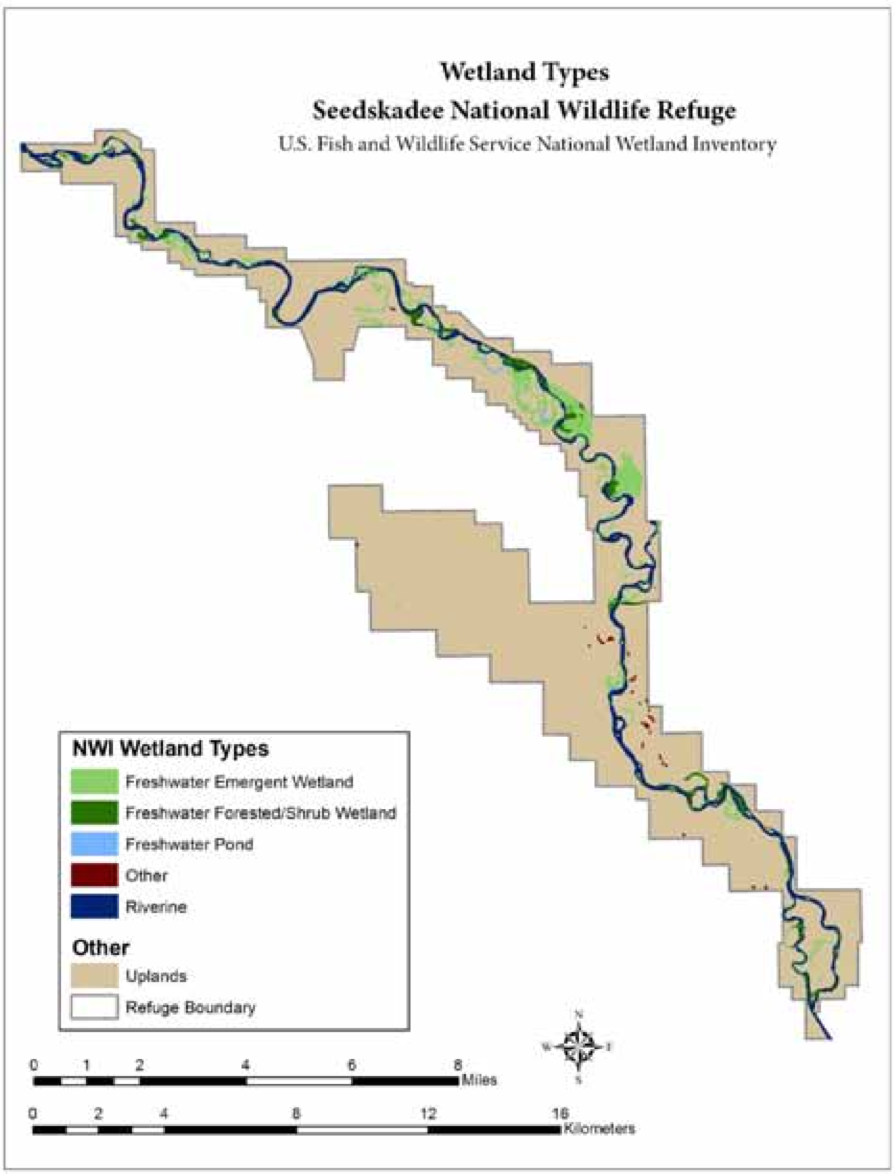

Figure 29. Wetland habitat types on Seedskadee National Wildlife Refuge as classified by the USFWS National Wetland Inventory, based on imagery from the 1980s.

Current riparian woodlands at Seedskadee NWR are aging and not being replaced (Glass 2002). Older cottonwood stands are showing signs of rapid deterioration, and without new recruitment. Alterations to abiotic factors that sustain riparian woodlands are being confounded by high browsing of existing cottonwood and willow by native ungulates and beaver and by higher rates of fire recurrence compared to historical levels (Scott et al. 2008) . Several attempts have been made to restock cottonwood in select riparian sites on the refuge using direct planting and fencing of saplings, but with minimal success (Glass 2002, Scott et al. 2008). Some direct plantings of upland species also have been conducted.

Few long term data are available to document changes in animal abundance and distribution at Seedskadee NWR. Information is best for select waterfowl species, sage grouse, and large ungulates (USFWS 2002). Generally, waterfowl numbers on the refuge have remained relatively stable and numerical changes in migrant numbers reflect continental/regional population dynamics. Trumpeter swans were reintroduced onto the refuge beginning in 1992 and the first successful nesting attempt occurred in 1997 when five cygnets were fledged (USFWS 2002). As many as five pairs of swans have nested on the refuge, but recent recruitment has been low. Mallard, gadwall, and cinnamon teal have been the most common nesting ducks, but nesting density and success currently is relatively low. Numbers of Canada geese (mostly the giant Canada goose subspecies, *Branta canadensis maxima*) nesting on the refuge has increased over time, as have giant Canada goose numbers across the Intermountain West area. Duck and goose production on Seedskadee NWR peaked in 1990 when approximately 1,800 ducklings and 300 Canada goose goslings were produced (USFWS, unpublished annual narratives up to 1999 and open files since). Little data are available on shorebird and wading bird numbers, but species associated with open water and dense stands of emergent vegetation such as American bittern, double-crested cormorant, American pelican, pied-billed grebe, black tern, American coot, and common moorhen may be more abundant than in pre-wetland impoundment periods. Likewise, other bird species associated with these habitats such as marsh wrens and yellow-headed blackbird may have increased over time. Numbers of sage grouse on the refuge appear stable; the status of other sagebrush-associated bird species is unknown.

Seedskadee NWR currently supports about 150 mule deer and 20-40 moose and pronghorns range year-round throughout the region. The refuge lies within the range of the Sublette Antelope herd, which at about 50,000 animals is one of the largest migratory ungulate herds in the lower 48 U.S. states. Many small mammals are abundant on the refuge, although some such as pygmy rabbit, marmot, swift fox, and bats may be declining (USFWS 2002). Black-footed ferret historically was present on Seedskadee NWR lands. A primary prey species, the white-tailed prairie dog currently is present on the refuge, but no known ferrets now are present.

Generally, native fish in the Green River system, including that at Seedskadee NWR, have declined and several species now are threatened or endangered. Many introduced, nonnative species now are present. Rainbow, cutthroat, and brown trout and Kokanee salmon were introduced into the Green River by the Wyoming Game and Fish Department after Fontenelle Reservoir was built. Prior to Fontenelle Dam, the stretch of the Green River at Seedskadee was warmer, more turbid, and had a more sediment-filled streambed. Post-Fontenelle, the river is less turbid, colder, and with a clearer gravel bottom – all of which may be more conducive to the nonnative trout species. In contrast, the turbulent river with turbid and higher temperatures that historically supported the four federally-endangered fish species in the Green River now is not present between Fontenelle and Flaming Gorge Dams.

Karen Kyle

Historical Photos
taken from Seedskadee NWR Annual Narratives

OPTIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

SUMMARY OF HGM INFORMATION

Information obtained in this study was sufficient to conduct an HGM evaluation of historic and current ecological attributes of the Seedskadee NWR ecosystem. Seedskadee NWR contains sections of the Green and Big Sandy Rivers and their floodplains embedded within the extensive desert-type sagebrush steppe community of southwest Wyoming. Historically, annual surface water inputs to the Seedskadee NWR ecosystem were provided by highly pulsed and dynamic discharges in the Green River during spring and early summer. Discharge levels and resulting flood flows into the Green River floodplain varied among years depending on annual snow pack and melt from surrounding mountains. The northern part of Seedskadee NWR was mainly influenced by Green River flows, while the southern part of the refuge also was influenced by flows from the Big Sandy River. Historically, Green River discharges peaked in May or June in most years and were sufficient (8,000 to 10,000 cfs) to cause at least some backwater flooding into old abandoned river channels, sloughs, and floodplain swales over 50% of the years prior to Fontenelle Reservoir. Larger flood events (> 14,000 cfs) appear to have inundated deeper floodplain depressions and occurred about every 5-10 years. Very large flood events > 20,000 were rare (only 3 times since the late 1800s) but were highly important to create extensive silt deposition and scouring, channel filling or migration, nutrient deposition, and extensive areas of floodplain connectivity. Similarly, regular flooding of the Big Sandy River maintained important ecological processes in its floodplain.

The regular river backwater flooding of low elevation floodplain wetlands every 2-5 years was a primary driving process that sustained the floodplain wetlands and wet meadows of the Seedskadee NWR region. Annual variation in Green River flows and subsequent overbank and backwater flooding likely caused significant annual variation in amount and distribution of flooded wetland area and corresponding persistent emergent, and seasonal herbaceous wetland vegetation communities in the floodplain. A narrow linear riparian woodland comprised of cottonwood and willow historically apparently was present along most areas of the Green and Big Sandy Rivers on natural levee and point bar surfaces. Large Green River flood events that exceeded 20,000 cfs apparently were critical to periodically provide deposition of fine alluvial sediments on natural levees and point bar ridges and/or scour clean some floodplain ridges where cottonwood and willow seedlings could periodically germinate and have adequate soil moisture to survive (Ikeda 1989).

The primary changes to the Seedskadee NWR ecosystem since major European settlement in the late 1800s, have been: 1) alterations to the amount, timing, duration, and extent of Green River flood waters flowing into and through riparian woodland and floodplain wetlands; 2) management of the distribution and retention of water in constructed and altered wetland impoundments and natural basins; 3) reduced presence, regeneration, and health of woody riparian vegetation; 4) altered sagebrush steppe species composition and distribution; and 5) increased presence of invasive species. A critical overriding issue that affects the future management of Seedskadee NWR is the annual operation of water storage and releases from Fontenelle Reservoir. A major challenge for future management of Seedskadee NWR will be to determine how a reduced flood-driven river system, likely affected by unknown future climate changes, will affect efforts to restore and provide critical habitats and communities for wildlife (Knopf et al. 1988, Meretsky et al. 2006, Seavy et al. 2009). Past attempts to plan management of the refuge have largely been designed to continue more permanent water management among wetland impoundments, which may or may not have been consistent with objectives that seek to restore and emulate natural distribution, abundance, and processes of endemic communities. Consequently, future management issues that affect timing, distribution, and movement of water on the NWR must consider how, and if, they are contributing to desired objectives of restoring native communities and their processes on the refuge. Additionally, future management and possible expansion of the refuge must seek to define the role of the refuge lands in a larger landscape-scale conservation and restoration strategy for the Upper Green River Basin and surrounding sagebrush steppe ecosystem.

GENERAL RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

This study is an attempt to evaluate restoration and management options that will protect, restore, and sustain natural ecosystem processes, functions, and values at Seedskadee NWR. Seedskadee NWR provides key resources to meet annual cycle requirements of many plant and animal species in the Upper Colorado River ecoregion of the western U.S. The Green River and its floodplains are an especially critical component of the river system that bisects an otherwise dry, semi-desert, ecosystem. Further, the sagebrush steppe habitats adjacent to the Green River in the Seedskadee NWR are part of the largest contiguous block of this habitat in the western U.S. This habitat supports populations of many animal species associated with this community in the Rocky Mountain ecoregion (USFWS 2010). Seedskadee NWR is an important area that also can provide opportunities for wildlife-dependent uses. These public uses are important values of the refuge, but they must be provided and managed within the context of more holistic regional landscape- and ecosystem-based management. This study does not address where, or if, the many sometimes competing uses of the refuge can be accommodated, but rather this report provides information to support The National Wildlife Refuge System Improvement Act of 1997, which seeks to ensure that the biological integrity, diversity, and environmental health of the (eco)system (in which a refuge sets) are maintained (USFWS 1999, Meretsky et al. 2006). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation; 2) assessment of each refuge's importance across landscape scales; and 3) recognition that restoration of historical processes is critical to achieve goals (Mertetsky et al. 2006). Most of the CCPs completed for NWRs to date, including the Seedskadee NWR CCP, have highlighted ecological restoration as a primary goal, and choose historical conditions (those prior to substantial human related changes to the landscape) as the benchmark condition (USFWS 2002, Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historical conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s) (USFWS 2001).

Given the above USFWS policies and mandates for management of NWRs, the basis for developing recommendations for the future management of Seedskadee NWR is the HGM approach used in this study. The HGM approach objectively seeks to understand: 1) how this ecosystem was created; 2) the fundamental physical and biological processes that historically "drove" and "sustained" the structure and functions of the system and its communities; and 3) what changes have occurred that have caused degradations and that might be reversed and restored to historic and functional conditions within a "new desired" environment. This HGM approach also evaluates the NWR within the context of appropriate regional and continental landscapes, and helps identify its "role" in meeting larger conservation goals and needs at different geographical scales. In many cases, restoration of functional ecosystems on NWR lands can help an individual refuge serve as a "core" of critical, sometimes limiting, resources than can complement and encourage restoration and management on adjacent and regional private and public lands.

Seedskadee NWR contains a relatively sharp contrast and dichotomy of communities/habitat types between the Green River and its floodplain and the adjacent upland sagebrush steppe landscape. The primary ecological process that controlled the Green River ecosystem was rising water levels in the Green River in spring and early summer that caused seasonal backwater flooding and inundation of at least some lower elevation floodplain sloughs, swales, and depressions in most years. Further, relatively regularly occurring (5-10 year periodicity) large flood events caused widespread inundation of floodplain areas and alluvial deposition/scouring events that formed dynamic topographic and water flow/soil saturation patterns in the floodplain. Both seasonal and longer term inter-annual river flow and flooding dynamics created and sustained a diversity of wetland types in the immediate floodplain and also created and sustained sites for riparian woodland germination and survival. The basic spatial and temporal pattern of this spring-flood driven ecosystem remains present, but operation of Fontenelle Dam has: 1) reduced flood peaks and frequency of spring/summer flows that caused extensive inundation and alluvial deposition/scouring in the floodplain; 2) caused artificial high flows in late summer and early fall; and 3) created high base flows in winter.

Floodplain topography and hydrology at Seedskadee NWR have been altered where extensive infrastructure has been constructed (e.g. dams, ditches, levees, water-control structures) to create and manage impounded wetlands for more permanent water regimes aimed at increasing waterfowl production. Concurrently, vegetation in wetland impoundments was dramatically changed from historic conditions where natural floodplain water regimes were predominantly seasonal and at best seimpermanent in deeper depressions. Natural wet meadow areas appear to be reduced in area and vigor on the refuge. In contrast, invasive species assemblages such as perennial pepperweed are increasing. Riparian woodland at Seedskadee NWR is rapidly deteriorating with almost no recruitment of new cottonwood seedlings and poor survival of existing trees from combined effects of fire, herbivory, and drought induced stress caused by infrequent floods and rapidly declining soil moisture in summer. Former riparian woodland is shifting to upland/grassland vegetation composition.

Upland areas on Seedskadee are driven by the relatively arid climate and geological history of the region. Low annual precipitation, high evapotranspiration rates, and sandy alkaline soils created a sagebrush steppe community throughout much of western Wyoming, southern Idaho, northern Nevada, and southern Oregon (West 1988). Herbivory and fire were important ecological drivers in this ecosystem, but fire was relatively infrequent and grazing was mainly by seasonally present large browsers and low numbers of granivores. After European immigration and settlement in southwestern Wyoming, this sagebrush community became heavily grazed by livestock, was burned more frequently, and many areas such as alluvial fans adjacent to floodplains or riparian areas (such as at Seedskadee NWR) were physically altered by roads, rail beds, fences, and ditches. Although livestock grazing now is reduced or eliminated on most of the uplands on Seedskadee NWR, the historical sagebrush steppe habitat is still greatly altered from the past grazing intensity that caused a reduction in abundance and distribution of native plant species including loss of native perennial bunchgrasses, expansion of some shrubs such as rabbitbrush, introduction of many annual weeds and grasses such as cheatgrass, and soil/slope erosion.

Clearly, Seedskadee NWR is, and will continue to be, highly affected by the presence and operation of Fontenelle Reservoir and Dam. The impetus for establishing Seedskadee NWR was to mitigate fish and wildlife habitat losses from the reservoir (and other older proposed diversions of water from the Green River). Consequently, future management of Seedskadee must attempt to sustain and restore historical communities and resources in this region of the Green River Valley and to manage all habitats (sagebrush steppe, floodplain wetlands, riparian woodland, riverine) to provide historical resources used and required by native animal species within the constraints imposed by the management of water storage and releases from Fontenelle Reservoir. Given this management context, and based on the HGM context of information obtained and analyzed in this study, we believe that future management of Seedskadee NWR should seek to:

1. Maintain and restore the physical and hydrological character of the Green River (below Fontenelle Reservoir) and the Big Sandy River as best possible.
2. Restore the natural topography, water regimes, and surface water flow and flooding patterns from the Green River into and across the Green River floodplain and sheetwater runoff into and across adjacent terraces and alluvial fans.
3. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

The following general recommendations are suggested to meet these ecosystem restoration and management goals for Seedskadee NWR.

1. Maintain and restore the physical and hydrological character of the Green River (below Fontenelle Reservoir) and the Big Sandy River as best possible.

The general physical position and geomorphology of the Green River below Fontenelle Dam have not been altered greatly, although several rock weirs and sills and other structures have been constructed to facilitate diversion of water into Seedskadee NWR impounded wetlands, provide watering gaps for livestock, and stabilize channel banks. Similarly, the physical nature of the lower Big Sandy River is only moderately altered from its historical condition. The Green River channel below Fontenelle Dam is not highly incised at present, but the reduced sediment loads in the river below the dam could potentially lead to eventual incision (Auble et al. 1997, Auble and Scott 1988, Glass 2002). The current low sediment loads in the Green River at Seedskadee NWR have an effect on downstream alluvial deposition in floodplains, which could alter nutrient levels and replenishment in floodplains, establishment of germination sites for riparian woodlands, and creation of topographic/bathymetry diversity and dynamics in the river that influence water velocity, turbidity, and structural features and diversity. In contrast, increased channel bank erosion that causes bank destabilization and increased sediment loading can occur where bank sites are altered by livestock, deforestation, and human activity. While no imminent large changes to the physical features of the Green or Big Sandy Rivers are foreseen, land managers must be vigilant to future proposals or actions that would alter the physical nature of the rivers and their inherent dynamics of flow and sediments and to smaller, cumulative changes in the physical integrity of the river channels and their floodplains.

In contrast to physical features, the hydrologic character of the Green River is greatly altered from the pre-Fontenelle Reservoir period. As currently operated, Fontenelle Reservoir has relatively little flexibility in water management as dictated by annual variation in watershed precipitation, water and land use, and downstream needs in the entire Colorado River system. Water flows in the Big Sandy River are less altered from historical periods, but still are affected to some degree by the reservoir on the river channel near Farson, Wyoming. Working closely with the BOR and negotiating water management guidelines for Fontenelle Reservoir will be important to a) maintain a more natural seasonal pattern of river discharge with a unimodal late spring-early summer discharge followed by gradual declines to low winter base levels, b) provide more regular (i.e., in ca. 50% of years if possible) peak flows > 8,000 to 10,000 cfs that allow at least some backwater flooding into floodplain sloughs, abandoned river channels, and swales; and c) occasionally allow high peak flows > 15,000 cfs that cause more extensive inundation of the Seedskadee NWR floodplain. Ideally, a flood discharge of > 20,000 cfs would occur about every 40 to 50 years to provide sediment and nutrient dynamics sufficient to create cottonwood regeneration sites, replenish nutrients and sediments in wetlands, and allow river migrations to occur.

Ultimately, the hydrology of the entire Green River ecosystem will depend on protecting the integrity of the upstream watersheds of the Green and Big Sandy Rivers with special emphasis on the more immediate lands in their floodplains and drainages. This need will require coordinated efforts of land owners and managers to protect surface and subsurface landscapes of the region including the geohydrology of the system. Vigilance against efforts to extract or divert more surface or subsurface water, alter flow patterns and pathways, and contamination of soils and water in the watersheds and floodplain corridors must be maintained.

2. Restore the natural topography, water regimes, and surface water flow and flooding patterns from the Green River into and across the Green River floodplain and sheetwater runoff into and across adjacent terraces and alluvial fans.

Many changes have occurred to the Seedskadee NWR floodplain from alterations in topography, water movement patterns, and water regimes. Certain of these changes have been directly caused by, or are associated with, construction and management of Fontenelle Reservoir. These include some past infrastructure that sought to move water to upland areas for irrigated croplands (e.g., the Hay Field area) and reduced spring discharge peaks that no longer flow into or through relict river channels, sloughs, and swales. Other changes occurred from construction of roads, water gaps, ditches, weirs, and water-control structures. Still other changes were purposeful attempts to modify natural flooding and drying regimes in wetlands to create more permanent and regularly occurring water regimes to increase open water and persistent emergent vegetation habitats and encourage waterfowl nesting. Collectively, these alterations have caused changes in vegetation communities and resources used and needed by select animal groups. If a goal of the refuge is to restore the naturally occurring physical and biotic diversity and productivity of the Seedskadee NWR ecosystem, then at least some restoration of natural topography, water flow pathways, and seasonal water regimes will be needed. This restoration will require changes in physical features and management of wetland impoundments.

First, an evaluation of all roads, ditches, weirs, fence lines, water gaps, etc. on the refuge should be made to determine if they are necessary, beneficial or detrimental to management objectives, and whether they can be modified or removed. As an example, some old small berms were constructed in floodplain wet meadow and grassland areas in an attempt to impound or divert water. If these structures disrupt sheetflow of runoff or flood water, disconnect natural swales or sloughs, or deter flood water movement into floodplain depressions they should be removed. Other infrastructure such as ditches formerly constructed to move water across floodplains for irrigation purposes, should be removed if they are not helpful to a desired wetland management need. Likewise, some internal levees constructed in impounded wetlands create impediments to independent water management among wetland units/pools and disrupt, or actually prevent, most floodwater levels from entering and flowing through the impoundments.

Second, the "new" lower flood pulse peaks on the Green River now seldom reach levels where river water can back or overflow into floodplain swales and depressions. Peak flows post-Fontenelle Reservoir average about 4,000 cfs lower than prior to the reservoir (e.g., Fig. 23), which equates to about a 2-4 foot lower river stage elevation at Seedskadee NWR during peak events. Where former river-floodplain connection entry points have been modified or artificially filled with sediment, they potentially could be reconnected and opened by excavating the fill material and lowering the natural levee entry points by 2-4 feet. Additionally, sediment or debris material that now obstructs or prevents flood flows in naturally occurring sloughs and swales should be removed. Clearing, deepening, and restoring natural water flow pathways will require careful engineering given the probability of new reduced flood flows in the Green River at Seedskadee NWR. While some deepening of sloughs and swales may be a bit artificial, it is consistent with attempting to restore the process of overbank and backwater flooding that was so critical to sustain this ecosystem.

Third, water management objectives for the individual wetland impoundments on Seedskadee NWR should be reviewed. Historically, the Green River floodplain at Seedskadee contained a diverse mosaic of depressions that reflected past river migration, alluvial deposition, and current scouring. The LIDAR maps for the refuge demonstrate this topographic diversity and the interrelationships of elevation and relative flooding regimes. Very few deep depressions occurred in the Seedskadee floodplain except for a few remnant oxbows and abandoned channels such as was within the Northern units (Fig. 16). These deeper wetlands apparently were regularly recharged by floodwaters on average about every 2-3 years and they probably retained at least some surface water throughout the summer and into fall. In very wet years, water likely was present throughout the year, while in dry years these deeper depressions may have had little if any water. Generally, few floodplain wetlands had water in late fall and winter at Seedskadee NWR; the only open water would have been in the river channel. The inter-annual dynamic flooding regimes in the deeper floodplain depressions helped maintain nutrient and vegetation cycling in these wetlands and attracted larger numbers of breeding waterbirds in wet years (see e.g., review in van der Valk 1989 and Heitmeyer and Fredrickson 2005). Most wetland depressions in the Green River floodplain at Seedskadee, however, were small swales in former ridge-and-swale river point bars. For example, the ridge-swale topography complexes in the Hamp, Pal, and Sagebrush units are marked (Fig. 6). These natural swales did not become inundated as often or as deeply as abandoned channel depressions, and the swales had seasonal water regimes that were recharged in spring and early summer and then dried relatively quickly into fall. Some higher elevation swale sites may have only contained a small amount of water from onsite precipitation or runoff in spring with rarer flooding by very large (and rare) flood events. Lower elevation swales likely flooded more regularly from moderate Green River flood events, especially those sites with connectivity to the river via backwater sloughs. Wet meadow habitats also were present in many floodplain locations that received only short duration sheetflow of water across relatively flat floodplain areas during spring flood and runoff events. These meadows did not impound water, except in shallow depressions, which dried quickly following inundation events.

Collectively, the HGM information for Seedskadee NWR indicate that most historical wetlands and wet meadows had seasonal water regimes and that even the deeper depressions had regular, perhaps almost annual, drying in late summer and fall. Consequently, wetland habitats were most extensive and available during spring and early summer and provided resources primarily to spring migrant waterbirds. During wet years more floodplain wetlands were inundated for longer periods in summer and attracted more waterbirds to stay and breed locally. Current water management of most wetland impoundments has overemphasized permanent and emergent vegetation for breeding waterbirds, and underemphasized seasonal flooding regimes most important for spring migrants, relative to historical pre-Fontenelle flooding regimes. Further, artificial high water levels and river discharge in fall and winter may be providing more fall/winter habitat for waterbirds and in the area, but at some ecological cost of altered water regimes and seasonal productivity of the sites.

3. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

Seven major vegetation communities (sagebrush steppe, mesic upland, floodplain grassland-wet meadow, seasonal herbaceous wetland, semipermanent emergent wetland, riparian woodland, and riverine) historically were present at Seedskadee NWR and they were distributed along geomorphic, soil, topographic, and flood frequency gradients (Table 8, Figs 20,21). Precise mapping of the potential historical distribution of these communities on Seedskadee NWR was constrained to some degree by coarse-scale soil mapping. In contrast, the recently completed LIDAR topographic information greatly enabled understanding of potential water regimes (Fig. 16). The spatial patterns of historical community distribution are relatively distinct (Table 8, Fig. 21). Obviously, riverine habitats were/are within active river channels and seasonally connected river chutes and sloughs. Deeper floodplain depressions, especially relict abandoned channel oxbows, contained open water-persistent emergent wetland habitats. Floodplain swales supported seasonal herbaceous communities while floodplain ridges and other relatively high floodplain area supported wet meadow habitats. Riparian forest was present on natural levees and other floodplain point bar ridge sites where alluvial deposition occurred and porous soils provided more prolonged and elevated groundwater during drying summer and fall periods. Uplands adjacent to floodplains, including alluvial fans that extended into the floodplain supported sagebrush steppe communities.

The above described community relationships with abiotic ecosystem attributes provides a guideline for determining which communities belong where in the Seedskadee NWR ecosystem, and which sites are appropriate for restoration of specific community types. For example, restoration of riparian forest, which is rapidly deteriorating, should be on relatively recent alluvial deposition/scour sites near the Green or Big Sandy Rivers (or seasonally connected abandoned river channels and sloughs) that have regular overbank/backwater flooding and prolonged soil moisture in the tree root zone through the growing season. Further, if natural recruitment of cottonwood cannot occur because of presently reduced occurrence of large flood events that deposit alluvial material and create bare soil surfaces for seed set and germination, then direct plantings of seedlings may be successful if they are in topographic and soil locations conducive to higher groundwater tables along the river (Scott et al. 1993, Braatne et al. 1996, Friedman et al. 1995). Future restoration and management of communities at Seedskadee NWR will require a careful evaluation of site characteristics to determine what the site historically supported and now is capable of supporting given alterations to the system.

SPECIFIC RECOMMENDATIONS FOR RESTORATION AND MANAGEMENT OPTIONS

Maintain and Restore the Physical and Hydrological Character of the Green and Big Sandy Rivers

The impetus for establishing Seedskadee NWR was the need to mitigate and protect a portion of the Green River and its floodplain following construction of Fontenelle Reservoir. Consequently, management of Seedskadee NWR must seek to protect and restore the section of the Green River ecosystem below Fontenelle within the constraints of the operation of Fontenelle Dam. As such, restoration and management of the refuge must clearly understand the ecological character of the river system prior to Fontenelle and identify the best options to protect and restore the physical and hydrological integrity of the river, its floodplain, and the associated communities it supported. Clearly, many issues related to the future management of the Green River are not under the control of the refuge, but the USFWS does have the opportunity and responsibility to manage Seedskadee NWR in an exemplary way that achieves its authorized purpose and contributes to the overall sustainability of the Green River system. Ultimately, achieving the greatest sustainability possible will require efforts to protect the upstream watershed of the Green and Big Sandy Rivers and work with BOR to manage water releases in the most natural flow regime possible. Specific actions that seem important to this end include:

1. Protect the physical integrity of the Green and Big Sandy Rivers and their upstream watersheds.

- Do not construct additional dams, levees, or channel-bank stabilization structures on the Green or Big Sandy rivers.
- Remove and do not place hard point or bank stabilization structures along the channel banks of the Green and Big Sandy rivers unless they protect critical property or structures.
- Remove, or place spillways in levees along the Green and Big Sandy rivers.
- Protect banks of rivers from physical disturbance, especially from livestock.
- If river channel incision begins to occur, carefully engineer rock weirs or other grade-control structures/measures, in the affected river area.
- Reconnect river channels with remnant side channels, abandoned channels, sloughs, and chutes.
- Encourage and participate in sustainable range management programs throughout the Upper Green River watershed.
- Protect alluvial fans and terraces along the Green and Big Sandy River valleys from detrimental development, mining, and topographic alteration and support private lands programs to maintain natural topographic features and communities.
- Evaluate opportunities to expand the boundaries and protection capabilities of Seedskadee NWR.
- Support programs to restore natural vegetation communities in areas of the Green River watershed that are potentially subject to high soil erosion and water intensive land uses including marginal agricultural lands.

2. Cooperate with the BOR to manage water releases from Fontenelle Reservoir in a more natural seasonal and inter-annual flow regime.

- Seek to maintain a more natural seasonal river flow regime of unimodal late-spring to early-summer peak discharges followed by gradual declines to low winter base levels in the Green River.
- Provide peak spring-early summer discharges of > 8,000 cfs whenever possible to provide at least some connectivity of river flood water with Green River floodplain wetland and off-channel depressions.
- In very wet years, seek to provide spring flood pulses as high as possible, preferably with occasional discharges > 15,000 cfs.
- Attempt to provide a high discharge of > 20,000 cfs about every 40 to 50 years.
- Reduce artificial high fall releases and discharges. Preferably, more water would be released in spring-summer and less in fall.

Restore Natural Topography, Water Flow Patterns, and Water Regimes

The restoration of historic ecological communities and their key driving ecological processes at Seedskadee NWR will require at least some restoration of natural topography, water flow patterns, and water regimes (e.g., Stanford et al. 1996). As stated above, part of this restoration will require achieving water releases from Fontenelle Reservoir that are more natural, both seasonally and long term. If these releases and more natural river flow regimes can be achieved, impediments to river-floodplain connectivity on the refuge should not be intentionally maintained, nor should present water management strategies in refuge wetland impoundments be preferred over natural flooding and drying regimes. The ultimate goal for Seedskadee NWR is to protect and restore natural integrity, functions, and values of the unique western riparian corridor and adjacent sagebrush steppe, and not try to create unnatural artificial conditions or communities on the refuge.

The inherent geomorphic surfaces, soils, topography, and former hydrology of wetland impoundments should be considered when deciding management and development strategies. Specific changes to the Seedskadee NWR system that seem helpful in this regard include:

1. ***Restore natural topography and reconnect natural water flow patterns and pathways where possible.***

- Evaluate all levees, roads, ditches, and water-control structures to determine if they are necessary, or are detrimental to, restoration of natural water flow patterns and water regimes in floodplains and uplands. Identify structures that can be used to help emulate natural flow patterns and conversely, remove or modify those structures that are not necessary or that are deterring natural water flow patterns.
- Do not construct additional wetland impoundments, roads, levees, or water-control structures that alter water flow into and across the floodplain.
- Restore at least some natural topography in wetland impoundments, and former agricultural lands that can be restored to native vegetation.
- Remove islands and deposition sites in wetlands.
- Improve water flow into and through historic floodplain abandoned channels, sloughs, and depressions by removing or lowering obstructions, levees, weirs, sills, and dams across these drainages and depressions.
- Evaluate the potential to "cut" fill material at entry points of relict floodplain channels, sloughs, and swales where the Green and Big Sandy Rivers would back or overflow into these sites. Also, remove or cut material from high spots in these channels that prohibit water movement through the floodplains and that could potentially flood extensive areas during high flow events.

2. ***Manage wetland impoundments and natural floodplain depressions for more natural seasonal and long-term water regimes based on their HGM-attribute position.***

- The Hamp Unit is located on an inside-bend point-bar geomorphic surface with a relict abandoned channel slough at the downstream end of the river bend where floodwaters from the Green River historically entered this area (Fig. 6a). The unit was originally developed into impoundments with the desire to create more permanent open-water emergent vegetation habitats for breeding waterfowl. Most of the unit is a classic river point-bar ridge-and-swale geomorphic surface where only short duration seasonal inundation occurred, except during high flow conditions on the Green River (Fig. 16a). Ideally, the unit should be managed as a more seasonally flooded wetland regime and seasonal herbaceous/wet meadow community. Infrastructure that deters floodwater entry from the bottom end of the unit should be modified or removed to allow high flow events to back into the abandoned channel sloughs and point bar swales.
- The Hawley Unit contains several natural topographic depression features including a relict abandoned channel oxbow (Figs. 6b,16b). The Green River also has two side chute channels adjacent to the floodplain. This area apparently has been a site of relatively recent river migration. Development of the site has diverted water into and through the unit to the more southern downstream impoundments and also created subdivided impoundments. The water management of impoundment pools typically has sought to create more permanent open water and emergent vegetation habitats. This management seems appropriate, but more natural dynamics of spring inundation followed by summer and fall drying should be encouraged. These semipermanent wetlands also periodically dried every 3-5 years when Green River peak flows in spring were low. Because water must be diverted into Hawley to supply water to downstream units, it is always flooded first and is flooded more regularly among years. Recognizing this "control" function, the unit should be occasionally dried to prevent the substantial encroachment and filling of the unit with dense monocultures of emergent vegetation, especially cattail. In the absence of more regular drying, other vegetation controls may be needed.
- The Lower Hawley Unit contains former channels of the Green River and a point bar ridge-and-swale geomorphic surface on the south end (Fig. 6c). The floodplain depressions in this area

likely flooded regularly when the Green River rose in spring and summer and the deeper relict oxbows may have been a large part of the more permanent wetlands in the system (Fig. 16c). Currently, water-control infrastructure moves water from the Hawley Unit into and through the unit, through the Sagebrush Unit, and finally to the southern Dunkle Unit. Several levees create subimpoundments in the Lower Hawley impoundment and they prevent high flows of the Green River from entering the unit. Managing water regimes and wetland vegetation in Lower Hawley in a manner similar to the Hawley Unit seems appropriate, and should include rotational flooding and drying of subimpoundments to emulate natural flooding-drying dynamics. Also, the outside levees of the impoundment should be evaluated to find appropriate potential breach or spillway sites where high flows of the Green River could enter the floodplain.

- The Pal Unit is a slightly higher elevation point bar river bend surface on the east side of the Green River and it includes a relict horseshoe-shaped abandoned river channel on the northeast side (Fig. 6c). The Unit historically contained riparian woodland along the river, seasonal herbaceous wetlands in swales and wet meadow grassland on ridges. The higher elevation areas in the unit historically apparently were flooded for short durations during spring flood events (Fig. 16c). Only a few water-control structures are present in the unit and they primarily are used to hold water in swales. Higher elevations in the unit are most suited for short duration seasonal flooding and wet meadow communities. In these areas existing water-control structures should be removed or modified to allow natural sheetwater flow from floodwater and runoff to occur. Deeper relict abandoned channel areas apparently had frequent inundation from high river flow events and probably had semipermanent water regimes that supported persistent emergent vegetation communities. Infrastructure should be evaluated to make sure river floodwater can continue to inundate these depressions frequently.

- The Sagebrush Unit is within a widely meandering portion of the Green River and includes point bar ridges and swales on two inside bends of the river with a cutoff abandoned channel behind the point bar (Fig. 6d). Historically, the high natural levees and probably ridges on point bars contained riparian woodland, the swales contained seasonal herbaceous wetlands, and the old cutoff river channel was semipermanent emergent wetland (Fig. 16d). Water currently is moved to the Unit from the upstream infrastructure associated with the Hawley units, and when river flows have been low, this and the Dunkle Unit have received less water. Consequently, the site has been developed to retain water in deeper areas of swales and the old oxbow. Future management and redesign of the unit should consider providing a complex of riparian woodland on ridges and the natural levee along inside point bar bends of the river, natural short duration seasonal flooding in swales, and more semipermanent water regimes in the old oxbow depression. Water-control structures that prevent high flows of the Green River from entering and inundating swales and depressions should be removed or modified.

- The Cottonwood Unit is a typical inside-bend point-bar surface that contains several ridge-and-swale topographic complexes. The swales in these areas apparently became inundated when river discharges exceeded 14,000 to 17,000 cfs; the entry point of flooding was at the downstream bottom ends of the river bends. In this unit all water-control structures that prevent occasional river backwater from entering the point-bar swales should be removed or modified to allow river flows to cross them.

- The Dunkle Unit contains a point-bar bend of the Green River, crevasse splays on the upper bend area, and old relict channels behind the point bar (Fig. 6e). The point bar bend has higher elevations and only shallow swales that probably historically supported riparian woodland and shrub wetland. Relict channels behind the point bar likely were flooded during high flow events of the Green River (Fig. 16e). The few water-control structures in the unit attempt to capture and hold water that is diverted from the upstream Hawley units. Because the unit is the farthest from the Hamp diversion point, it has a less regular water source. Given the less reliable source of water and its point bar setting, water-control structures should be removed if they deter floodwater entry during high Green River discharge times and where structures are retained, the water regimes should be seasonal.

Sustain and Restore Natural Vegetation Communities

The native mosaic of vegetation communities at Seedskadee NWR were important components of the Green River ecosystem and the entire Upper Colorado River ecoregion. Sustaining, and restoring where necessary, the distribution and types of historical habitats is important to the long term capability of the entire ecoregion to support system functions, values, and services. The general types and distribution of communities at Seedskadee NWR have not changed dramatically from historic patterns, but the following major alterations have occurred:

- Upland sagebrush steppe has altered species composition including invasion by nonnative annual grasses and weeds.
- Riparian woodlands are rapidly deteriorating and almost no natural recruitment of cottonwood is occurring.
- Many floodplain wetland depressions have been impounded with more permanent water regimes and open water-emergent vegetation and less seasonal herbaceous and wet meadow communities.
- Off channel side and high flow channels, sloughs, swales, and oxbows have been disconnected with the Green River.

Restoration and maintenance of native communities seems possible and desirable (at least to certain degrees) at Seedskadee NWR. Consequently, the basis for future conservation, restoration, and management of plant communities on Seedskadee NWR should be guided by ecological attributes identified in the HGM matrix and maps provided in this report based on geomorphology, soil, topography, and hydrology features (Table 8, Fig. 21). Specific actions to assist this restoration include:

1. Protect and restore native vegetation composition to upland sagebrush steppe areas.

- Protect all existing sagebrush steppe areas from conversion to other habitat types, fragmentation, and disturbance from livestock and vehicles.
- Encourage natural fire regimes, with long return intervals, in uplands and especially in drainage areas and washes.
- Carefully manage some decadent sagebrush areas with select thinning and reduce the occurrence and extent of rabbitbrush where it is artificially high.
- Control invasive weeds and grasses.

2. Restore linear bands of riparian woodland along the Green and Big Sandy Rivers.

- Attempt to maintain existing areas of riparian woodland with protection from extensive browsing and trampling from native ungulates and livestock and suppression of fires.
- Work with BOR to restore more natural flow regimes in the Green River (see earlier recommendations section) that include: 1) occasional high discharges that can flood higher elevation natural levees and ridges in floodplains, 2) gradual declines in water levels (< 4 cm/day) in summer, and 3) low base flows in winter (to prevent excessive water levels and ice scouring).
- Target restoration sites that have sandy loam soils on natural levees of active and relict river channels and sloughs and ridges in point bar river bend areas where high, more sustained, groundwater levels occur during summer. These sites typically are on inside bend point bar sites.
- Evaluate some use of physical disturbance in the above sites to provide bare-soil surfaces for cottonwood and willow seed set and germination. In sites where no seed source or bare soils are present, plant seedlings with protective wire or wrap to prevent browsing and damage to seedlings from ungulates and beaver (e.g., Glass 2002, Breck et al. 2003, Scott et al. 2008).
- Continue monitoring and evaluation studies on biotic and abiotic components of riparian woodland communities and restoration efforts.

3. Restore complexes of floodplain wetland communities with natural water regimes.

- Restore connectivity of the Green River and floodplain depressions and restore water flow pathways in floodplains as suggested previously.
- Change infrastructure and management of wetland impoundments as listed above.
- Control invasive plants in floodplains and restore native species composition to wet meadow areas.

- Manage wetland impoundments for annually dynamic water regimes and reduce monotypic stands of tall emergents, especially cattail, to increase productivity of semipermanent wetland areas such as relict oxbows.

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MONITORING AND EVALUATION

Future management of Seedskadee NWR should include regular monitoring and directed studies to determine how ecosystem structure and function are changing, regardless of whether restoration and management options identified in this report are undertaken. Ultimately, the success in restoring and sustaining communities and ecosystem functions/values at Seedskadee NWR will depend on how well the physical and hydrological integrity of the Green River Valley is protected and how key ecological processes and events, especially pulsed late-spring and early-summer flooding, can be restored or emulated by management actions. Uncertainty exists about the ability to make some system changes because of constraints of Fontenelle Reservoir management, water rights and historical uses, and land uses in the larger Green River watershed, including the Big Sandy River drainage. Also, techniques for controlling or reducing introduced plant species and restoring cottonwood are not entirely known.

Whatever future management actions occur on Seedskadee NWR, activities should be done in an adaptive management framework where: 1) predictions about community response and water issues are made (e.g., improved distribution and vigor of seasonal wetland communities in floodplain swales) relative to specific management actions (e.g., restoring floodplain connectivity at discharge levels of 8-10,000 cfs) and then 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action.

The availability of geospatial (e.g., LIDAR) and hydrological data (e.g., flow dynamics) for the Green River system greatly enhanced the ability of this HGM evaluation to identify potential management options for Seedskadee NWR. Further, past research and monitoring studies of certain communities, especially riparian woodlands, and attributes (such as groundwater dynamics) have been critically important in advancing the understanding of the Seedskadee NWR ecosystem. Other important data needed to more precisely understand HGM relationships and management options are not available, however. The most important of these missing data are: 1) precise stage-discharge relationships for the Green River at various locations on the refuge, 2) detailed contemporary soils data and maps, and 3) historical photographs that identify pre-Fontenelle Dam features and flood events in the Green River floodplain. If these data, maps, and photographs become available, the HGM relationships, maps, and recommendations provided in this report likely can be refined.

Especially critical information and monitoring needs for Seedskadee NWR are identified below:

KEY BASELINE ECOSYSTEM DATA

Important site- and regionally-specific data that are needed for the Seedskadee NWR region include:

- Detailed soils mapping and description, especially within the alluvial floodplain areas.
- Comprehensive inventory and mapping of all vegetation, including invasive and noxious species.
- Comprehensive surveys of key animal species that represent major taxa, species of concern or management emphasis, and primary trophic levels.
- Presence, depth, and duration of water levels in off-channel floodplain areas associated with various river stage levels.

RESTORING NATURAL WATER REGIMES AND WATER FLOW PATTERNS

This report suggests several physical and management changes to help restore some more natural topography, water flow, and flooding dynamics in floodplain habitats. Most changes involve restoring at least some more natural water flow through natural drainages and tributaries and across floodplain meadows in a sheetflow manner and to manage depressions and impounded sites for more seasonally- and annually-dynamic flooding and drying regimes. The following monitoring will be important to understand effects of these changes if implemented:

- Annual monitoring of water use for refuge areas including source, delivery mechanism or infrastructure, extent and duration of flooding/drying, and relationships with non-refuge water and land uses. These data will also document how existing water rights are used and maintained.
- Documentation of how water moves across floodplain areas at various river stage levels, especially during flow events > 8,000 cfs.
- Evaluation of surface and groundwater interactions and flow across and through alluvial fans and terraces onto floodplain areas and eventual discharge into the Green River.
- Periodic monitoring of water quality in all drainage and floodplain areas.
- Refinement of topographic, roughness, and hydraulic data used in the HEC-RAS models (discussed earlier in the Historical Climate and Hydrology section).

LONG TERM CHANGES IN VEGETATION AND ANIMAL COMMUNITIES

As previously stated, comprehensive baseline data on historic, and even current, plant and animal communities for Seedskadee NWR is sparse. In addition to determining current distribution and dynamics of species, long term survey/monitoring programs are needed to understand changes over time and in relation to management activities (e.g., USFWS 2007). Important survey/monitoring programs are needed for:

- Distribution and composition of major plant communities including expansion or contraction rates of introduced and invasive species.
- Survival, growth, and regeneration rates of willow and cottonwood in riparian woodland corridors.
- Abundance, chronology of use, survival, and reproduction of key waterbird and Neotropical migrant songbirds such as dabbling ducks, trumpeter swan, American bittern, etc.
- Occurrence and abundance of ungulates.
- Occurrence and abundance of amphibians, reptiles, and fish.

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APPENDIX A

1 Hydraulic Analysis Overview

A hydraulic analysis of the Green River through Seedskadee National Wildlife Refuge was completed for flow rates of: 5,000 cfs; 14,000 cfs; 17,000 cfs; 20,000 cfs; and 25,000 cfs. The analysis utilized Light Detection and Ranging (LiDAR) for the elevation data. ArcMap and HEC-GeoRAS used the LiDAR data to create the input data for HEC-RAS. HEC-RAS computed the water surface elevations for the various flows. Finally, HEC-RAS created the output which was used as an input to ArcMap to create flooding maps.

2 HEC-RAS Description

HEC-RAS is software from the U.S. Army Corps of Engineers' Hydrologic Engineering Center's River Analysis System. HEC-RAS performs hydraulic calculations for natural and constructed channels. HEC-RAS contains four analysis components for: steady flow water surface profile computations; unsteady flow simulation; movable boundary sediment transport computations; and water quality analysis (Brunner, 2010).

The Seedskadee analysis is limited to the steady flow water surface profile computations only, which computes water surface elevation for a constant flow rate at all points in the river. Multiple flow rates were analyzed, however only one flow rate was analyzed in each run, rather than changing the flow rate at different points along the river.

The computational procedure is based on the solution of the one-dimensional energy equation. This entails calculating energy losses by Manning's equation and contraction/expansion. The effects of various obstructions such as bridges, culverts, weirs, levees, spillways and other structures in the flood plain may be considered in the computations (Brunner 2010).

3 HEC-GeoRAS Description

HEC-GeoRAS is an ArcGIS® extension designed to process geospatial data (i.e. LiDAR) for use with HEC-RAS. The tools allow users to create an HEC-RAS import file containing geometric attribute date from existing terrain models. Water surface profile results created by HEC-RAS may also be processed to visualize inundation depths and boundaries (Ackerman 2009).

4 Manning Equation Discussion

As described above, HEC-RAS utilizes Manning's equation to compute water surface elevations. Manning's equation is dependent upon: 1) the cross sectional shape of the river; 2) the surface roughness of the channel and; 3) the slope of the water surface.

The cross sectional area of the river can be accurately modeled for the areas that were *above* water at the time of the LiDAR survey only. LiDAR does not penetrate water, so the cross sectional area of the river *beneath* the water surface at the time of the LiDAR survey must be approximated.

The cross section of the river was approximated by modifying the LiDAR data in ArcMap. This was accomplished by first identifying the edge of the water. The line defining the edge of the water was then offset in towards the middle of the river a distance of 3 meters (9.8 ft) horizontally on both sides of the river. All LiDAR points between this offset line and the water edge were lowered 0.3 meters (1 ft). Next, the line defining the edge of the water was offset in towards the middle of the river a distance of 5 meters (16.4 ft) horizontally on both sides of the river. All LiDAR points between these offset lines were lowered a distance of 1 meter (3.3 ft). The figure below shows the original channel from the LiDAR data, as well as the approximated channel.

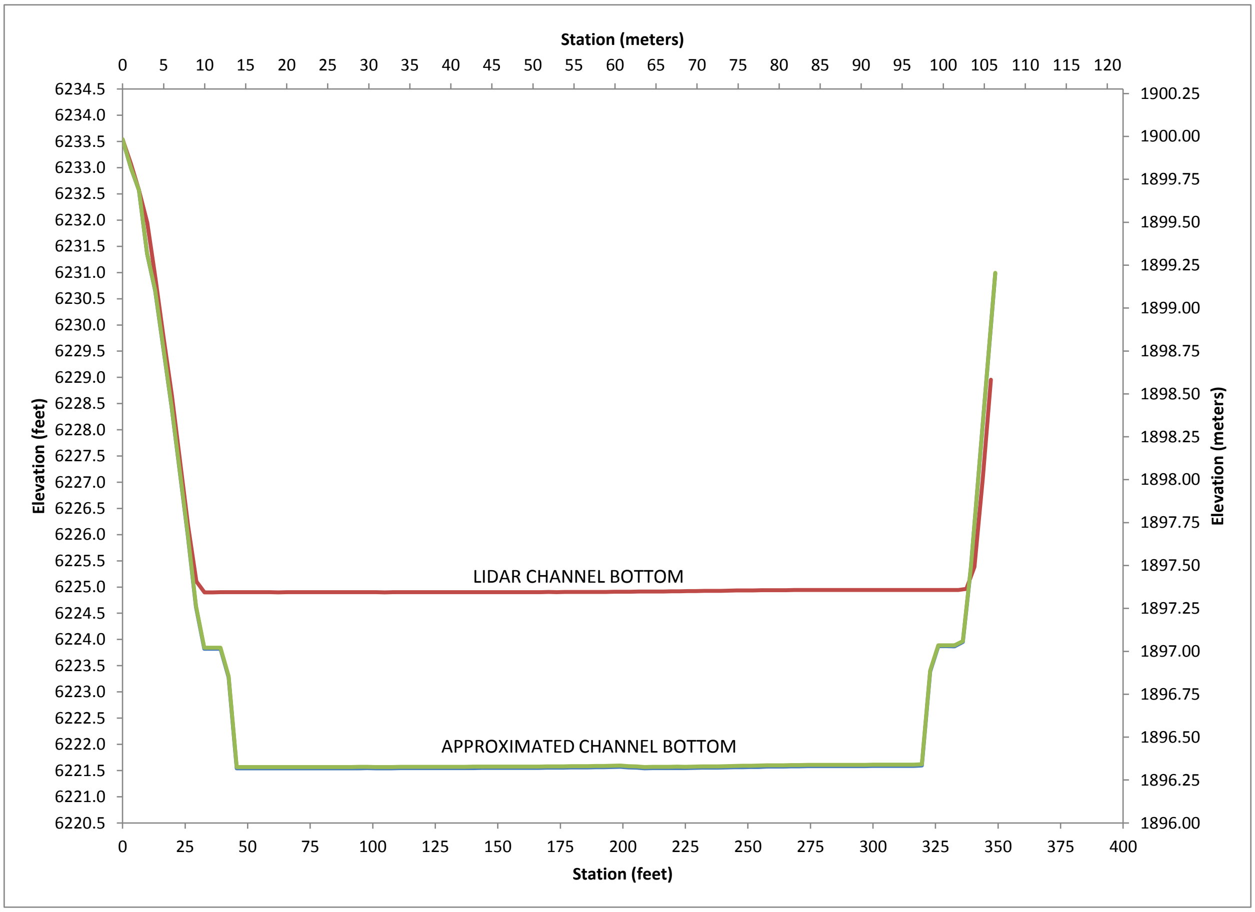

Figure 4-1: River Cross Section modifications for HEC-RAS modeling

The surface roughness of the channel, also known as manning's value, varies greatly along a river reach and with different stages of flow. Channels with heavy vegetation have more surface roughness than a grass channel for example. The roughness of a channel can also vary throughout the year, as the height of vegetation will increase the surface roughness. For this modeling effort, Manning's number for the channel was set to 0.039. Manning's number for the floodplain was set to 0.05.

Knowing that the cross sectional shape cannot be perfectly modeled, and that the exact channel roughness cannot be perfectly modeled is important in evaluating the results of HEC-RAS. For example a 17,000 cfs flow may flood a significantly different area if the flood occurs during the summer or winter.

The HEC-RAS results shown are associated with a specific flow rate (i.e. 14,000 or 17,000 cfs), however it must be understood that the results are produced with average surface roughness values and an approximate river channel, therefor actual flood inundation may be above or below the results shown.

5 Modeling Results Discussion

The output of the HEC-RAS was compared to historical aerial imagery during floods and during base flows. The areas HEC-RAS predicted to be flooded appeared very similar to historical flooding images. The LiDAR data proved to be extremely beneficial to accurately map the areas that are inundated by flooding. Although the area of inundation shown is associated with specific flows, it is understood that the exact extent of flooding will likely vary. It may be useful to create flooding classifications such as minor, moderate, and extreme which correlate to a range of flows.

5.1 Recommended Modeling Improvements

Although the results are very useful, there are modifications to the model than can be completed if more detail is required.

Additional survey information should be collected for the areas within the channel that could not be penetrated by LiDAR. In order to collect the amount of data necessary to pair with the LiDAR data, an extremely labor intensive ground survey can be completed. Alternatively, LiDAR can be flown during an extreme drought event. Or, there are LiDAR technologies that are becoming more common that can penetrate water.

In addition to the survey modifications, HEC-RAS can model hydraulic features such as: 1) levees; 2) varied flows; 3) bridges; and 4) split flows. These capabilities were not utilized as it was determined the results produced accurately reflected historical aerial photography.

5.1.1 Levees

HEC-RAS will assume that the water surface across a cross section is constant. For example, if there is a ditch that parallels the river, it will assume that the water level in the ditch is the same level as the river. This assumption typically is valid, except in cases where the ditch is not connected to the river on the upstream or downstream end of the ditch. For example if the ditch has been plugged, or if stoplogs are in place, then the ditch may not be correctly modeled. Using the levee tools in HEC-RAS can be used to model these areas more accurately.

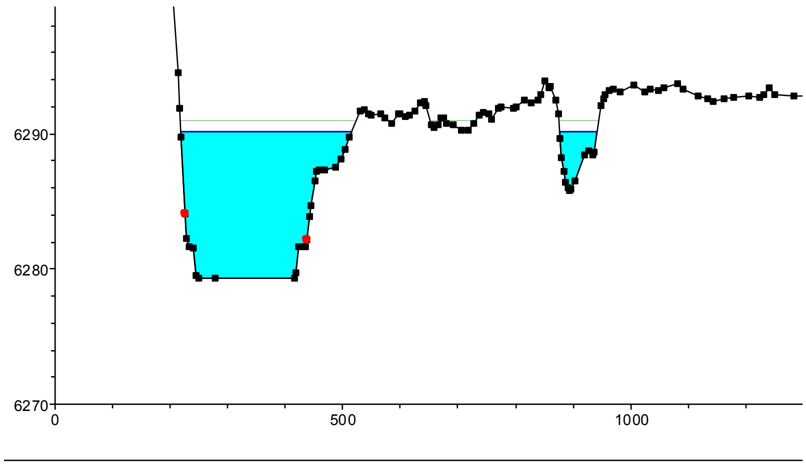

Figure 5-1: Cross section showing flow in parallel ditch

5.1.2 Varied Flow

The hydraulic analysis was a steady state analysis, in that one flow rate was modeled throughout the entire river. If it is determined that the flow rates increase downstream due to tributaries that enter the river, or if it is determined that the flow rates decrease downstream due to withdrawals, then an unsteady flow simulation can be computed.

5.1.3 Bridges

There are two bridges that cross the Green River in this reach. It was determined that the bridges did not significantly impact the water profile and the effects of the bridges would be limited to an area immediately adjacent to the bridge, so the bridge analysis was not completed. Multiple cross sections were samples around the bridge, so it is unlikely the results would change significantly.

5.1.4 Split Flow

Similar to the discussion regarding levees, HEC-RAS can accurately model river splits. For example where there is an island (i.e. Big Island or Telephone Island) the river splits and flows around the island. It is possible that the water surface across the cross section is not exactly level, and it would be more accurate to model the river as a river split rather than using a single cross section.

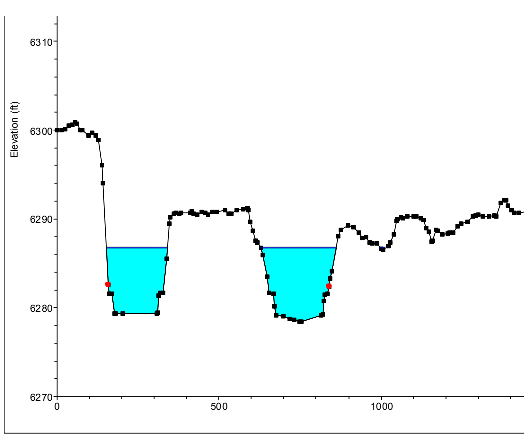

Figure 5-2: Cross section showing split flow

6 Lower Hawley Analysis

The Lower Hawley area is a good area to illustrate the uses of HEC-RAS as well as the limitations.

Lower Hawley is an area with extensive dike construction and ditch construction within the floodplain.

Figure 6-1: 2009 Aerial Image showing ditches (in blue) and levees (in yellow)

This is an area that appears to have had water in the pools which are formed from the ditches and dikes at the time of the LIDAR survey.

Figure 6-2: LIDAR elevation map

Looking at a profile of the LIDAR data for the portion of the Hawley Unit, it is apparent the LIDAR data reflects the top of the pools (flat surfaces), rather than the “real” ground.

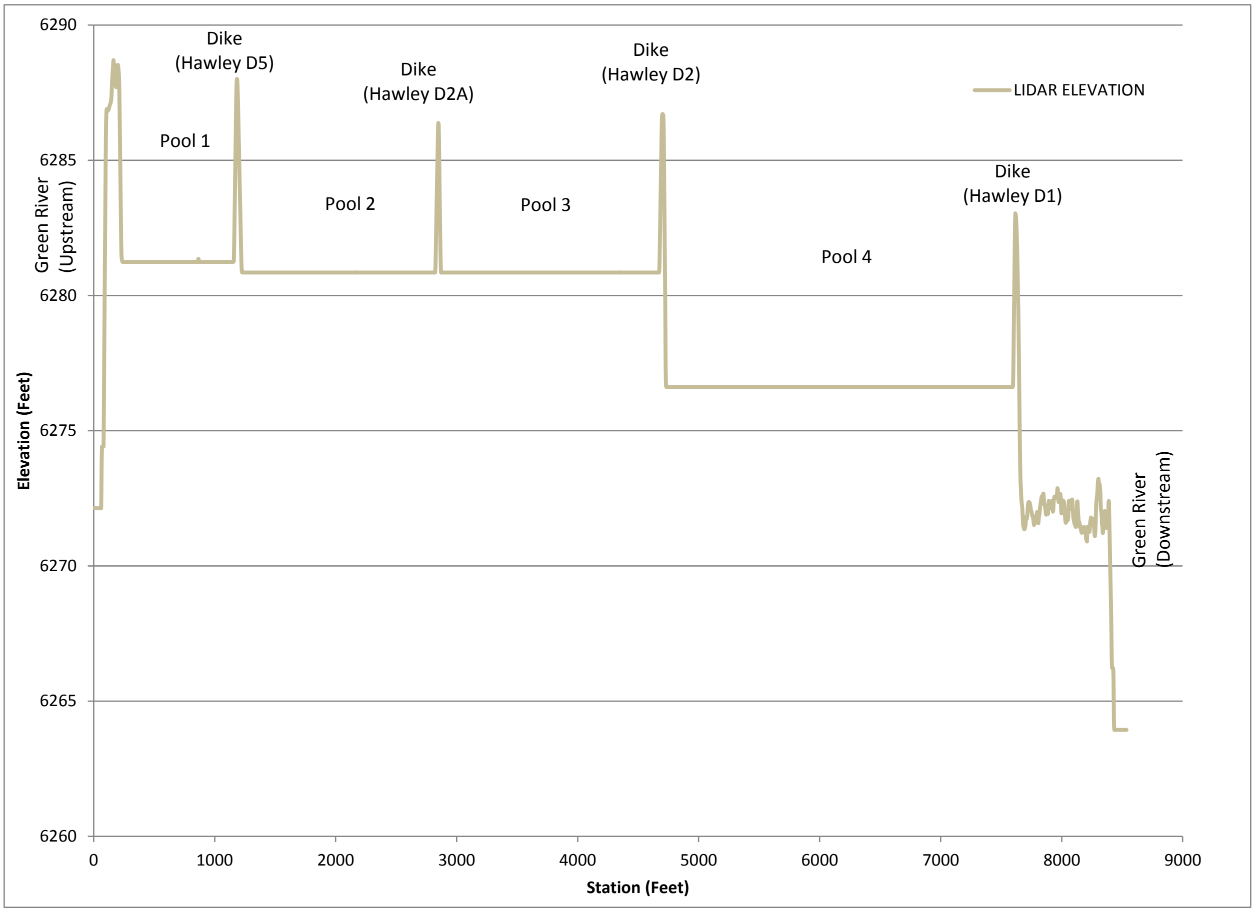

Figure 6-3: LIDAR Profile of Off-Channel Pools at Hawley Unit

The HEC-RAS model results for a moderate flood (approximately 14,000)show the following inundated areas. As can be seen from the HEC-RAS inundation map, the downstream (south) end of many pools are not inundated.

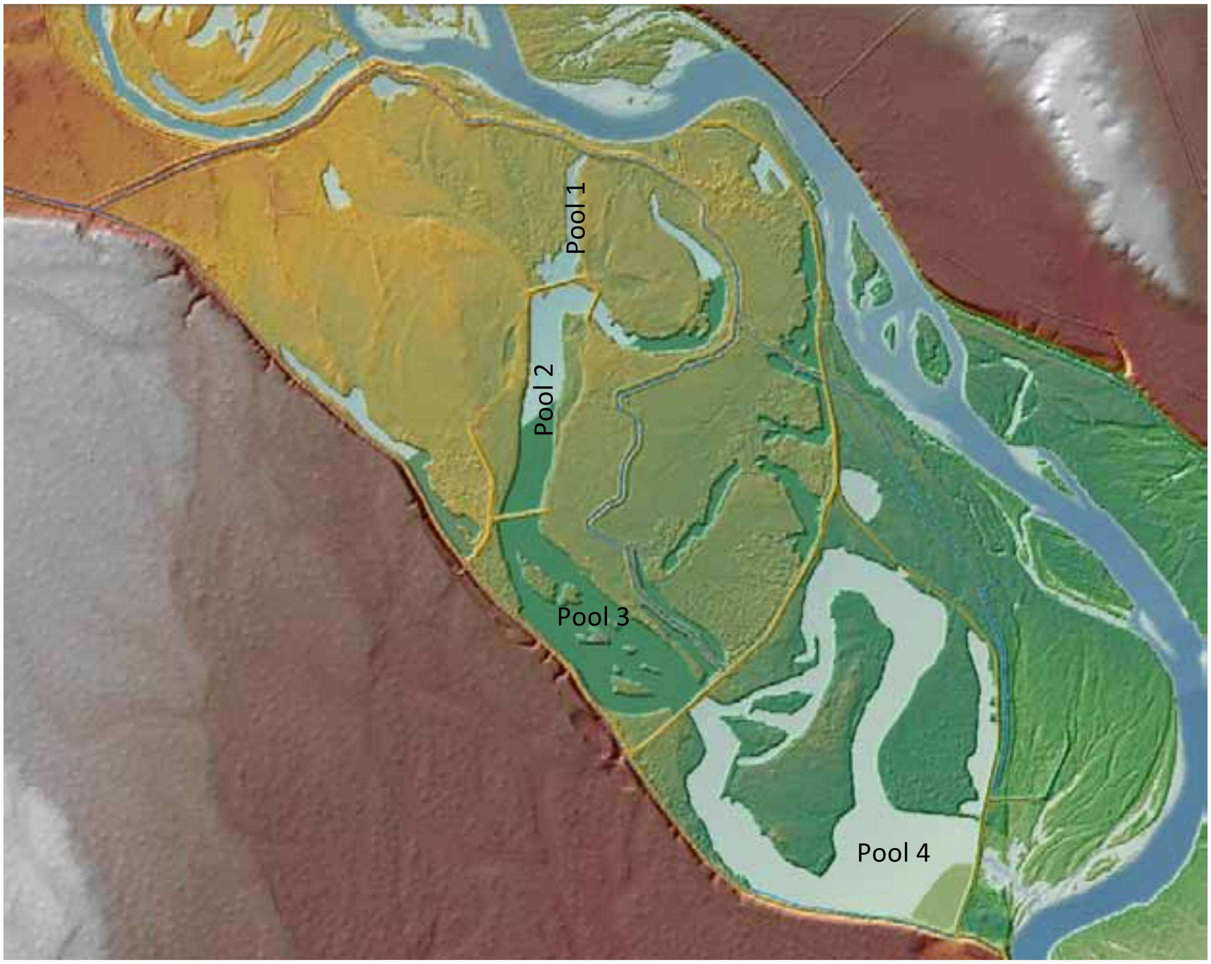

Figure 6-4: Lower Hawley Inundation Map (dark blue indicate deep water, light blue indicates shallow water)

Only the upper portions of the off-channel ponds appear to be flooded because the LIDAR results show the elevation of the land above the calculated water surface elevation from HEC-RAS. The profile below shows the calculated water surface as well as the LIDAR elevations. Notice on the lower ends of the ponds, the LIDAR elevation is above the water surface.

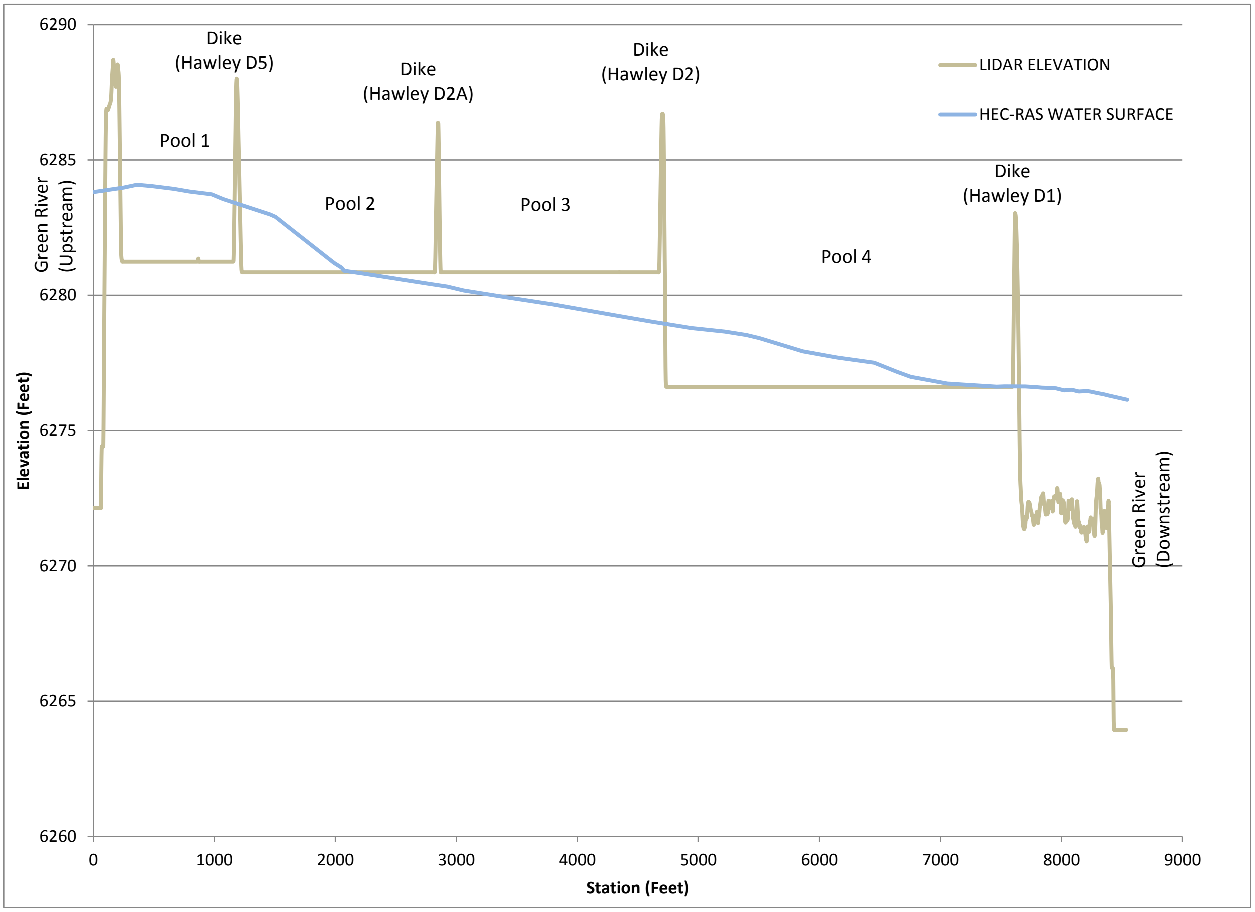

Figure 6-5: LIDAR and Water Surface in Off-Channel Ponds at Hawley Unit

In order to correctly model the Hawley unit, the pools that were filled with water would need to be resurveyed. An approximate “real” ground surface, would look similar to the following graph.

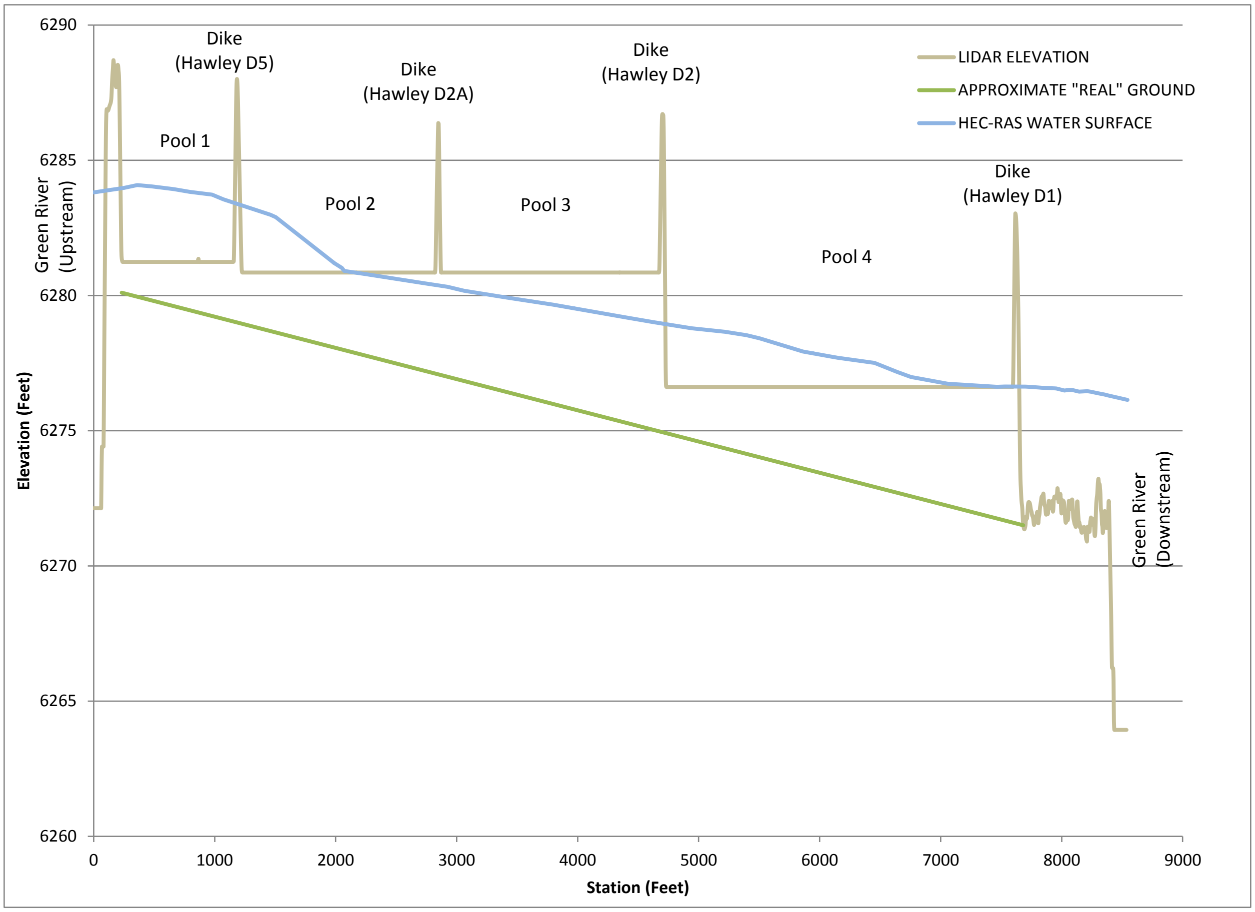

Figure 6-6: LIDAR, Water Surface, and Approximate "Real" Ground in Off-Channel Ponds at Hawley Unit

In the above graph, the water surface would be more of a constant depth of approximately 3-4 feet, rather than the depth of 0-3 feet calculated by HEC-RAS.

In order to accurately model these ponds that were filled during the LIDAR survey, it would be beneficial to resurvey these areas and re-run the HEC-RAS model.

In addition, these off-channel areas should be carefully evaluated for times when HEC-RAS predicts flooding. There may be a moderate flood occurring in the main channel, but if the infrastructure prevents water from entering the ponds, these areas may be dry during a flood even though the HEC-RAS analysis predicts flooding. This is an example of the levee function of HEC-RAS, where flooding outside the main channel will occur only if a certain threshold is reached, which would push water over the top of the levees.

Appendix B. Vegetation species expected to occur in vegetation community types on Seedskadee National Wildlife Refuge. For status, N=native, I=introduced/invasive, and I*=noxious weed designated by the State of Wyoming. For growth type, A=annual, B=biennial, and P=perennial.

Common Name	Scientific Name	Habitats							Status	Growth Type
		Wetland					Upland			
		River	Riparian	Emergent	Wet Meadow	Saline Playa	Grassland	Sagebrush		
FERN ALLIES										
Equisetaceae (Horsetails)										
Smooth Horsetail	*Equisetum laevigatum*		x		x				N	P
MONOCOTS										
Alismataceae										
Broadlead arrowhead	*Sagittaria latifolia*		x	x	x				N	P
Amaryllidaceae										
Wild Onion	*Allium textile*						x	x	N	P
Cyperaceae (Sedges)										
Douglas' Sedge	*Carex douglasii*		x		x	x	x	x	N	P
Woolly Sedge	*Carex pellita*		x		x	x	x		N	P
Nebraska Sedge	*Carex nebrascensis*				x				N	P
Clustered Field Sedge	*Carex praegracilis*		x		x	x			N	P
Northwest Territory Sedge	*Carex utriculata*		x	x	x				N	P
Short-beaked/ Analogue Sedge	*Carex simulata*		x	x	x	x			N	P
Common Spikerush	*Eleocharis palustris*		x	x	x	x			N	P
Hardstem/Tule Bulrush	*Schoenoplectus acutus*		x	x					N	P
Common threesquare	*Schoenoplectus pungens*		x	x					N	P
Iridaceae										
Rocky Mountain Iris	*Iris missouriensis*		x		x				N	P
Blue-eyed Grass	*Sisyrinchium* spp.		x		x				N	P
Juncaceae (Rushes)										
Baltic Rush	*Juncus arcticus*		x		x	x			N	P
Juncaginaceae										
Seaside Arrowgrass	*Triglochin maritima*		x	x	x	x			N	P
Lilaceae										
Sego Lily	*Calochortus nuttallii*						x	x	N	P
Starry Solomon's Seal	*Maianthemum stellatum*		x		x				N	P
Najadaceae										
Naiads	*Najas* sp.								N	A
Poaceae (Grasses)										
Crested Wheatgrass	*Agropyron cristatum*						x	x	I	P
Bluebunch Wheatgrass	*Pseudoroegneria spicata*				x		x	x	N	P
Redtop, Bentgrass	*Agrostis gigantea*				x		x		I	P
Shortawn Foxtail	*Alopecurus aequalis*		x		x				N	P
Creeping Foxtail	*Alopecurus arundinaceus*		x		x	?			I	P
Meadow Foxtail	*Alopecurus pratensis*		x		x		x		I	P
American Sloughgrass	*Beckmannia syzigachne*		x	x	x				N	A
Smooth Brome	*Bromus inermis*				x		x		I	P

Common Name	Scientific Name	Habitats: Wetland: River	Wetland: Riparian	Wetland: Emergent	Wetland: Wet Meadow	Wetland: Saline Playa	Upland: Grassland	Upland: Sagebrush	Status	Growth Type
Cheatgrass	*Bromus tectorum*						x	x	I	A
Northern Reedgrass	*Calamagrostis stricta*		x		x				N	P
Tufted Hairgrass	*Deschampsia cespitosa*				x				N	P
Inland Saltgrass	*Distichlis spicata*					x			N	P
Basin Wildrye	*Leymus cinereus*				x		x	x	N	P
Intermediate Wheatgrass	*Thinopyrum intermedium*				x		x	x	I	P
Quackgrass	*Elymus repens*						x	x	I*	P
Western Wheatgrass	*Pascopyrum smithii*					x		x	N	P
Slender Wheatgrass	*Elymus trachycaulus*				x	x	x	x	N	P
Meadow Fescue	*Schedonorus pratensis*				x		x	?	I	P
Galleta	*Pleuraphis jamesii*					x	x	x	N	P
Foxtail Barley	*Hordeum jubatum*					x			N	P
Scratchgrass	*Muhlenbergia asperifolia*		x		x	x			N	P
Mat Muhly	*Muhlenbergia richardsonis*		x		x	x	x		N	P
Indian Ricegrass	*Achnatherum hymenoides*					x	x	x	N	P
Reed Canarygrass	*Phalaris arundinacea*		x	x	x				N/I	P
Timothy	*Phleum pratense*		x		x		x	x	I	P
Common Reed	*Phragmites australis*		x	x					N	P
Alkali/Sandberg Bluegrass	*Poa secunda*					x	x	x	N	P
Kentucky Bluegrass	*Poa pratensis*		x		x		x	x	I	P
Bottlebrush squirreltail	*Elymus elymoides*						x	x	N	P
Alkali Cordgrass	*Spartina gracilis*		x			x			N	P
Alkali Sacaton	*Sporobolus airoides*					x	x	x	N	P
Needle and Thread	*Hesperostipa comata*						x	x	N	P
Potamogetonaceae										
Pondweeds	*Potamogeton* sp.	x		x					N	P
Narrow-leaved pondweeds	*Stuckenia* sp.	x		x					N	P
Typhaceae										
Broadleaf Cattail	*Typha latifolia*		x	x					N	P
DICOTS - FORBS										
Apiaceae										
Water Hemlock	*Cicuta maculata*		x	x	x				N	P
Plains Spring-parsley	*Cymopterus glomeratus*							x	N	P
Longstalk Springparsley	*Cymopterus longipes*							x	N	P
Asclepiadaceae										
Showy Milkweed	*Asclepias speciosa*		x		x		x		N	P
Asteraceae										
Russian Knapweed	*Acroptilon repens*		x		x		x	x	I*	P
Pale Agoseris	*Agoseris glauca*				x		x		N	P

Common Name	Scientific Name	Habitats: Wetland: River	Riparian	Emergent	Wet Meadow	Saline Playa	Habitats: Upland: Grassland	Sagebrush	Status	Growth Type
Littleleaf Pussytoes	*Antennaria parvifolia*		x				x	x	N	P
Tarragon Sagewort	*Artemisia dracunculus*		x				x	x	N	P
Louisiana Wormwood/ White Sagebrush	*Artemisia ludoviciana*		x		x		x	x	N	P
Pacific or Western Aster	*Symphyotrichum ascendens*						x	x	N	P
Musk Thistle	*Carduus nutans*		x		x	x	x	x	I*	A,B
Spotted Knapweed	*Centaurea stoebe*						x	x	I*	B,P
Canada Thistle	*Cirsium arvense*		x		x	x	x	x	I*	P
Elk Thistle	*Cirsium foliosum*				x		x	x	N	P
Bull Thistle	*Cirsium vulgare*		x		x		x		I	B
Dandelion Hawksbeard	*Crepis runcinata*		x		x		x	x	N	P
Smooth Fleabane	*Erigeron glabellus*							x	N	B,P
Low Fleabane	*Erigeron pumilus*							x	N	P
Curlycup Gumweed	*Grindelia squarrosa*		x			x	x	x	N	A,B,P
Stemless Goldenweed	*Stenotus acaulis*						x	x	N	P
Lanceleaf Goldenweed	*Pyrrocoma lanceolata*		x		x		x	x	N	P
Nuttall Goldenweed/ Rayless Tansyaster	*Xanthisma grindelioides*							x	N	P
Common Sneezeweed	*Helenium autumnale*		x		x				N	P
Fineleaf Hymenopappus	*Hymenopappus filifolius*						x	x	N	P
Poverty Weed	*Iva axillaris*					x	x	x	N	P
Prickly Lettuce	*Lactuca serriola*						x	x	I	A,B
Skeletonplant	*Lygodesmia grandiflora*		x		x		x	x	N	P
Purple Aster/ Hoary Tansyaster	*Dieteria canescens*						x	x	N	A,B,P
Water Groundsel/ Water Ragwort	*Senecio hydrophilus*		x		x	x			N	B,P
Missouri Goldenrod	*Solidago missouriensis*						x	x	N	P
Marsh Sow-thistle	*Sonchus arvensis* ssp. *uliginosus*		x		x		x		I*	P
Spiny Sow-thistle	*Sonchus asper*		x		x		x		I	A
False Sagebrush/ Silver Chicken-sage	*Sphaeromeria argentea*							x	N	P
Common Dandelion	*Taraxacum officinale*		x		x		x	x	N/I	P
Hoary Townsend Daisy	*Townsendia incana*							x	N	A,B,P
Common Cocklebur	*Xanthium strumarium*		x		x	x	x	x	N	A
Boraginaceae										
Roughseed Cryptantha	*Cryptantha flavoculata*							x	N	P
Silky Cryptantha	*Cryptantha sericea*							x	N	B,P
Western Sticktight	*Lappula occidentalis*						x	x	N	A

Common Name	Scientific Name	Habitats: Wetland: River	Riparian	Emergent	Wet Meadow	Saline Playa	Habitats: Upland: Grassland	Sagebrush	Status	Growth Type
Narrow-leaf Gromwell	*Lithospermum incisum*						x	x	N	P
Nuttall's Crinklemat	*Tiquilia nuttallii*							x	N	A
Brassicaceae										
Holboell's Rockcress	*Arabis holboellii*							x	N	B,P
Hoary Cress	*Cardaria draba*		x		x	x	x	x	I*	P
Longstalk Whitetop	*Cardaria pubescens*		x		x	x	x	x	I*	P
Pinnate Tansy-mustard	*Descurainia pinnata*						x	x	N	A,B
Flixweed Tansy-mustard	*Descurainia sophia*						x	x	I	A,B
Halimolobos	*Halimolobos virgata*						x	x	N	B,P
Tall Whitetop/ Pepperweed	*Lepidium latifolium*		x	x	x	x	x	x	I*	P
Clasping Pepperweed	*Lepidium perfoliatum*						x	x	I	A,B
Alpine Bladderpod	*Lesquerella alpina*							x	N	P
Foothill Bladderpod	*Lesquerella ludoviciana*						x	x	N	P
Malcolmia	*Malcolmia africana*							x	I	A
Sharpleaf Twinpod	*Physaria acutifolia*							x	N	P
Bluntleaf Yellowcress	*Rorippa curvipes*		x		x				N	A,P
Spreading Yellowcress	*Rorippa sinuata*		x		x				N	P
Flaxleaf Plainsmustard	*Schoenocrambe linifolia*						x	x	N	P
Capparaceae										
Yellow beeplant	*Cleome lutea*		x		x		x	x	N	A
Caryophyllaceae										
Hooker Sandwort	*Arenaria hookeri*							x	N	P
Baby's Breath	*Gypsophila paniculata*		x				x	x	I	P
Ceratophyllaceae										
Coontail	*Ceratophyllum demersum*	x		x					N	P
Chenopodiaceae										
Oakleaf Goosefoot	*Chenopodium glaucum*		x	x	x	x			I	A
Slimleaf Goosefoot	*Chenopodium leptophyllum*						x	x	N	A
Saltlover/Common Halogeton	*Halogeton glomeratus*						x	x	I	A
Kochia	*Kochia scoparia*		x		x		x	x	I	A
Poverty-weed	*Monolepis nuttalliana*		x			x			N	A
Rocky Mountain Glasswort	*Salicornia rubra*					x			N	A
Russian Thistle	*Salsola tragus*						x	x	I	A
Convolvulaceae										
Field Bindweed	*Convolvulus arvensis*		x				x	x	I*	P
Euphorbiaceae										
Horned/Rocky Mountain Spurge	*Euphorbia brachycera*							x	N	P
Ridgeseed Spurge	*Chamaesyce glyptosperma*						x	x	N	A

Common Name	Scientific Name	Habitats							Status	Growth Type
		Wetland					Upland			
		River	Riparian	Emergent	Wet Meadow	Saline Playa	Grassland	Sagebrush		
Fabaceae										
Purple/Field Milkvetch	*Astragalus agrestis*				x		x	x	N	P
Silver-leafed Milkvetch	*Astragalus argophyllus*					x		x	N	P
Canada Milkvetch	*Astragalus canadensis*					x		x	N	P
Cicada Milkvetch	*Astragalus chamaeleuce*							x	N	P
Lesser Rushy Milkvetch	*Astragalus convallarius*							x	N	P
Geyer's Milkvetch	*Astragalus geyeri*							x	N	A,B
Green River Milkvetch	*Astragalus pubentissimus*							x	N	A,B,P
Woollypod Milkvetch	*Astragalus purshii*						x	x	N	P
Tufted Milkvetch	*Astragalus spatulatus*						x	x	N	P
Looseflower Milkvetch	*Astragalus multiflorus*							x	N	P
American Licorice	*Glycyrrhiza lepidota*		x				x		N	P
Silvery Lupine	*Lupinus argenteus*		x				x	x	N	P
Rusty Lupine	*Lupinus pusillus*		x				x	x	N	A
Alfalfa	*Medicago sativa*				x		x	x	I	P
White Sweet-clover	*Melilotus albus*		x		x		x	x	I	A,B,P
Yellow Sweet-clover	*Melilotus officinalis*		x		x		x	x	I	A,B,P
Drop-pod Locoweed	*Oxytropis deflexa*		x		x		x		N	P
River Oxytrope	*Oxytropis riparia*		x						I	P
Silky Crazyweed	*Oxytropis sericea*		x				x	x	N	P
Lemon Scurfpea	*Psoralidium lanceolatum*							x	N	P
Swaison Pea	*Sphaerophysa salsula*					x	x	x	I	P
Intermountain Clover	*Trifolium andinum*							x	N	P
American Vetch	*Vicia americana*		x		x	x	x	x	N	P
Hippuridaceae										
Common Marestail	*Hippuris vulgaris*	x	x	x					N	P
Hydrophyllaceae										
Leafy Nama	*Nama densum*							x	N	A
Lamiaceae										
Field/Wild Mint	*Mentha arvensis*		x		x				N	P
False Dragonhead	*Physostegia parviflora*		x		x				N	P
Malvaceae										
Scarlet Globemallow	*Sphaeralcea coccinea*						x	x	N	P
Nyctaginaceae										
Narrowleaf four o'clock	*Mirabilis linearis*						x	x	N	P
Snowball Sand Verbena	*Abronia fragrans*						x	x	N	P
Sandpuffs	*Tripterocalyx micranthus*						x	x	N	A
Onagraceae										
Small Evening Primrose	*Camissonia minor*							x	N	A

Common Name	Scientific Name	Habitats							Status	Growth Type
		Wetland					Upland			
		River	Riparian	Emergent	Wet Meadow	Saline Playa	Grassland	Sagebrush		
Barestem Evening Primrose	*Camissonia scapoidea*							x	N	A
Scarlet Gaura	*Gaura coccinea*						x		N	P
Tufted Evening Primrose	*Oenothera caespitosa*						x	x	N	P
Hooker's Evening Primrose	*Oenothera elata* ssp. *hirsutissima*		x				x	x	N	B,P
Hairycalyx/Pale Evening Primrose	*Oenothera pallida*						x	x	N	B,P
Hairy Evening Primrose	*Oenothera villosa*		x		x		x	x	N	B,P
Orobanchaceae										
Clustered Broomrape	*Orobanche fasciculata*						x	x	N	A
Plantaginaceae										
Redwood Plantain	*Plantago eriopoda*					x			N	P
Broadleaf Plantain	*Plantago major*		x				x	x	I	P
Polemoniaceae										
Hood's Phlox	*Phlox hoodii*						x	x	N	P
Sand Gilia	*Aliciella leptomeria*						x	x	N	A
Common Ball-head Gilia	*Ipomopsis congesta*						x	x	N	P
Prickly Phlox	*Leptodactylon pungens*							x	N	P
Polygonaceae										
Nodding Buckwheat	*Eriogonum cernuum*						x	x	N	A
Cushion Buckwheat	*Eriogonum ovalifolium*						x	x	N	P
Prostrate Knotweed	*Polygonum aviculare*		x		x	x	x	x	I	A,P
Curly Dock	*Rumex crispus*		x		x		x		I	P
Canaigre Dock	*Rumex hymenosepalus*		x			x	x		N	P
Golden Dock	*Rumex maritimus*		x		x				N	A,B
Primulaceae										
Sea Milkwort	*Glaux maritima*					x			N	P
Ranunculaceae										
Alkali Buttercup	*Ranunculus cymbalaria*		x		x	x			N	P
Rosaceae										
Common Silverweed	*Argentina anserina*		x		x				N	P
Woolly Cinquefoil	*Potentilla hippiana*				x		x	x	N	P
Santalaceae										
Bastard Toadflax	*Comandra* sp.		x				x	x	N	P
Scrophulariaceae										
Indian Paintbrush	*Castilleja angustifolia*						x	x	N	P
Bushy Bird's Beak	*Cordylanthus ramosus*		x		x		x	x	N	A
Sand Penstemon	*Penstemon arenicola*							x	N	P
Fuzzytongue Penstemon	*Penstemon eriantherus*						x	x	N	P
Fremont's Beardtongue	*Penstemon fremontii*							x	N	P
Water Speedwell	*Veronica anagallis-aquatica*	x	x						I	P

Common Name	Scientific Name	Habitats							Status	Growth Type
		Wetland					Upland			
		River	Riparian	Emergent	Wet Meadow	Saline Playa	Grassland	Sagebrush		
Solanaceae										
Black Henbane	*Hyoscyamus niger*						x	x	I	A,B
Buffalobur Nightshade	*Solanum rostratum*						x	x	I	A
Valerianaceae										
Edible Valeriana/ Tobacco Root	*Valeriana edulis*				x		x		N	P
Verbenaceae										
Prostrate Vervain	*Verbena bracteata*		x		x		x	x	N	A,B,P
DICOTS - TREES & SHRUBS										
Asteraceae										
Fringed Sagebrush	*Artemisia frigida*						x	x	N	P
Black Sagebrush	*Artemisia nova*							x	N	P
Bud Sagebrush	*Picrothamnus desertorum*						x	x	N	P
Big Sagebrush	*Artemisia tridentata*							x	N	P
Green Rabbitbrush	*Lorandersonia linifolia*							x	N	P
Rubber Rabbitbrush	*Ericameria nauseosa*							x	N	P
Snakeweed	*Gutierrezia sarothrae*							x	N	P
Gray horsebrush	*Tetradymia canescens*							x	N	P
Cottonthorn horsebrush	*Tetradymia spinosa*							x	N	P
Anacardiaceae										
Skunkbush/ Fragrant Sumac	*Rhus trilobata*						x	x	N	P
Betulaceae										
Water Birch	*Betula occidentalis*		x						N	P
Cactaceae										
Prickly Pear Cactus	*Opuntia* sp.						x	x	N	P
Pincushion Cactus	*Pediocactus simpsonii*						x	x	N	P
Chenopodiaceae										
Shadscale Saltbush	*Atriplex confertifolia*							x	N	P
Gardner's Saltbush	*Atriplex gardneri*						x	x	N	P
Spiny Hopsage	*Grayia spinosa*						x	x	N	P
Black Greasewood	*Sarcobatus vermiculatus*							x	N	P
Cornaceae										
Red-osier	*Cornus sericea*		x		x				N	P
Elaeagnaceae										
Silverberry/Wolf Willow	*Elaeagnus commutata*		x						N	P
Russian Olive	*Elaeagnus angustifolia*		x		x	x	x		I	P
Silver Buffaloberry	*Shepherdia argentea*		x		x		x	x	N	P

Common Name	Scientific Name	Habitats							Status	Growth Type
		Wetland					Upland			
		River	Riparian	Emergent	Wet Meadow	Saline Playa	Grassland	Sagebrush		
Grossulariaceae										
Wax/Golden Currant	*Ribes aureum*		x		x		x	x	N	P
Missouri/ Redshoot Gooseberry	*Ribes oxyacanthoides* ssp. *setosum*		x						N	P
Polemoniaceae										
Granite Prickly Phlox	*Leptodactylon pungens*						x	x	N	P
Polygonaceae										
Umbrella Plant/ Shortstem Buckwheat	*Eriogonum brevicaule*		x		x		x	x	N	P
Rosaceae										
Wood's Rose	*Rosa woodsii*		x						N	P
Salicaceae										
Narrowleaf Cottonwood	*Populus angustifolia*		x						N	P
Bebb Willow	*Salix bebbiana*		x						N	P
Coyote Willow	*Salix exigua*		x			x			N	P
Whiplash Willow	*Salix lucida* ssp. *caudata*		x						N	P
Solanaceae										
Matrimony Vine/ Chinese Boxthorn	*Lycium barbarum*		x						I	P
Tamaricaceae										
Salt Cedar	*Tamarix ramosissima*		x						I*	P

Karen Kyle

Appendix C. Fish, amphibian and reptile, mammal, and bird species expected to occur in vegetation community types on Seedskadee National Wildlife Refuge.

Common Name	Scientific Name	Habitats							
		Wetland					Upland		
		River	Riparian	Emergent	Wet Meadow	Saline Playa	Grassland	Sagebrush	Other
FISH									
Rainbow Trout*	*Oncorhynchus mykiss*	x							
Brown Trout*	*Salmo trutta*	x							
Lake Trout*	*Salvelinus namaycush*	x							
Snake River Cutthroat Trout*	*Oncorhynchus clarki ssp.*	x							
Bear River Cutthroat Trout*	*Oncorhynchus clarki utah*	x							
Colorado River Cutthroat Trout***	*Oncorhynchus clarki pleuriticus*	x							
Kokanee Salmon*	*Oncorhynchus nerka*	x							
Mountain Whitefish	*Prosopium williamsoni*	x							
Channel Catfish*	*Ictalurus punctatus*	x							
Smallmouth Bass*	*Micropterus dolomieu*	x							
Colorado Pikeminnow***	*Ptychocheilus lucius*	x							NR
Mottled Sculpin	*Cottus bairdii*	x							
White Sucker*	*Catostomus commersonii*	x							
Mountain Sucker	*Catostomus platyrhynchus*	x							
Flannelmouth Sucker***	*Catostomus latipinnis*	x							
Bluehead Sucker***	*Catostomus discobolus*	x							
Razorback Sucker***	*Xyrauchen texanus*	x							NR
Common Carp*	*Cyprinus carpio*	x							
Utah Chub*	*Gila atraria*	x							
Roundtail Chub***	*Gila robusta*	x							
Humpback Chub***	*Gila cypha*	x							NR
Bonytail Chub***	*Gila elegans*	x							NR
Bonneville Redside Shiner*	*Richardsonius balteatus hydrophlox*	x							
Fathead Minnow*	*Pimephales promelas*	x							
Speckled Dace	*Rhinichthys osculus*	x							
AMPHIBIANS									
Northern Leopard Frog***	*Lithobates pipiens*			x	x		x		
Boreal Chorus	*Pseudacris triseriata*		x	x	x	x	x		
Great Basin Spadefoot***	*Spea intermontana*		x					x	
Tiger Salamander	*Ambystoma tigrinum*		x	x	x	x	x	x	
REPTILES									
Many-lined Skink	*Eumeces multivirgatus*						x	x	Rocky
Northern Sagebrush Lizard	*Sceloporus graciosus graciosus*							x	MMS

	Northern Plateau Lizard***	*Sceloporus undulates elongatus*								x		Rocky Cany.
	Eastern Short-horned Lizard	*Phrynosoma douglassii brevirostre*							x	x		Rocky
	Eastern Yellow-bellied Racer	*Coluber constrictor flaviventris*		x		x	x		x	x		
	Great Basin Gopher Snake	*Pituophis catenifer deserticola*		x	x	x	x		x	x		
	Wandering Western Terrestrial Garter	*Thamnophis elegans vagrans*		x	x	x			x			
	Western Plains Garter Snake	*Thamnophis radix haydenies*		x		x	x		x			
BIRDS												
Gaviiformes												
	Common Loon***	*Gavia immer*	x		x							
Podicipediformes												
	Horned Grebe	*Podiceps auritus*	x		x							
	Eared Grebe	*Podiceps nigricollis*			x							
	Pied-billed Grebe	*Podylimbus podiceps*	x		x							
	Western Grebe***	*Aechmophorus occidentalis*			x							
	Clark's Grebe***	*Aechmorphorus clarkii*			x							
Pelicaniformes												
	American White Pelican***	*Pelecanus erythrorhynchos*	x		x							
	Double-crested Cormorant	*Phalacrocorax auritus*	x	x	x							
Ciconiformes												
	American	*Botaurus lentiginosus*			x							
	Great Blue Heron	*Ardea herodias*	x	x	x							
	Great Egret	*Ardea alba*	x	x	x	x						
	Snowy Egret***	*Egretta caerulea*		x	x	x						
	Cattle Egret	*Bubulcus ibis*	x	x	x	x	x		x			
	Black-crowned Night Heron***	*Nycticorax nycticorax*	x	x	x	x	x					
	White-faced	*Plegadis chihi*			x	x	x					
Anseriformes												
	Trumpeter Swan***	*Cygnus buccinator*	x	x	x	x						
	Tundra Swan	*Cygnus columbianus*	x	x	x	x						
	Canada Goose	*Branta canadensis*	x	x	x	x						
	Ross's Goose	*Chen rossi*			x	x						
	Lesser Snow Goose	*Chen caerulescens caerulescens*			x	x						
	Wood Duck	*Aix sponsa*	x	x	x							
	Mallard	*Anas platyrhunchos*	x	x	x	x	x		x	x		
	Gadwall	*Anas strepera*			x	x	x					
	Northern Pintail	*Anas acuta*			x	x	x					
	American Wigeon	*Anas americana*		x	x	x			x	x		
	Northern Shoveler	*Anas clypeata*			x	x	x		x	x		
	Cinnamon Teal	*Anas cyanoptera*			x	x	x					
	Blue-winged Teal	*Anas discors*			x	x	x					
	Green-winged	*Anas crecca*		x	x	x	x		x	x		
	Canvasback	*Aythya valisineria*	x		x							
	Redhead	*Aythya americana*	x		x		x					
	Ring-necked Duck	*Aythya collaris*	x		x							
	Lesser Scaup	*Aythya affinis*	x		x	x			x	x		

	Long-tailed Duck	*Clangula hyemalis*	x									
	Common Goldeneye	*Bucephala clangula*	x		x							
	Barrow's Goldeneye	*Bucephala islandica*	x	x	x							
	Bufflehead	*Bucephala albeola*	x		x							
	Hooded Merganser	*Lophodytes cucullatus*	x	x	x							
	Common Merganser	*Mergus merganser*	x	x	x							
	Red-breasted Merganser	*Mergus serrator*	x	x								
	Ruddy Duck	*Oxyura jamaicensis*	x		x							
Falconiformes												
	Turkey Vulture	*Cathartes aura*	x	x	x	x	x		x	x		Rocky
	Northern Harrier	*Circus cyaneus*	x	x	x	x	x		x	x		
	Sharp-shinned Hawk	*Accipiter striatus*		x						x		
	Cooper's Hawk	*Accipiter coperii*		x						x		
	Northern Goshawk***	*Accipiter gentillis*		x						x		
	Swainson's Hawk***	*Buteo swainsoni*		x		x	x		x	x		
	Red-tailed Hawk	*Buteo jamaicensis*		x	x	x	x		x	x		
	Ferruginous Hawk***	*Buteo regalis*		x	x	x	x		x	x		
	Rough-legged Hawk	*Buteo lagopus*		x	x	x	x		x	x		
	Golden Eagle	*Aquilla cyrysaetos*	x	x	x	x	x		x	x		Cany.
	Bald Eagle***	*Haliaeetus leucocephalus*	x	x	x	x	x		x	x		
	Osprey	*Pandion haliaetus*	x	x	x							
	Merlin***	*Falco columbarius*		x	x	x	x		x	x		
	American Kestrel	*Falco sparverius*				x	x		x	x		
	Prairie Falcon	*Falco mexicanus*				x	x		x	x		Cliff
	Peregrine Falcon***	*Falco peregrinus*	x	x	x	x	x		x	x		MMS
Galliformes												
	Greater Sage-grouse***	*Centrocercus urophasianus*		x		x	x		x	x		
Gruiformes												
	American Coot	*Fulica americana*	x		x							
	Common	*Gallinula chloropus*			x							
	Virginia Rail	*Rallus limicola*			x	x	x					
	Sora	*Porzana carolina*			x	x	x					
	Sandhill Crane	*Grus canadensis*		x	x	x	x		x	x		
	Whooping	*Grus americana*			x	x	x		x			
Charadriiformes												
	Black-bellied Plover	*Pluvialis squatarola*		x		x	x					Rocky
	Semipalmated Plover	*Charadrius semipalmatus*		x		x	x					
	Killdeer	*Charadrius*				x	x					Rocky
	Mountain	*Charadrius montanus*					x		x	x		
	American Avocet	*Recurvirostra americana*		x	x	x	x		x			
	Black-necked Stilt	*Himantopus mexicanus*			x	x	x					
	Greater	*Tringa melanoleuca*	x	x	x	x	x					

	Lesser Yellowlegs	*Tringa flavipes*	x	x	x	x	x					
	Solitary Sandpiper	*Tringa solitaria*		x		x	x					
	Willet	*Tringa semipalmata*	x			x			x			
	Spotted	*Actitis macularia*	x	x	x	x	x		x	x		
	Upland Sandpiper	*Bartramia longicauda*							x	x		
	Long-billed Curlew***	*Numenius americanus*				x	x		x			
	Marbled Godwit	*Limosa fedoa*			x	x	x		x			
	Semipalmated Sandpiper	*Calidris pusilla*			x	x	x					
	Western Sandpiper	*Calidris mauri*			x	x	x					
	Least Sandpiper	*Calidris minutilla*		x	x	x	x					
	Baird's Sandpiper	*Calidris bairdii*	x	x	x	x	x					
	Pectoral	*Calidris melanotos*		x		x	x		x			
	Stilt Sandpiper	*Calidris himantopus*			x	x	x					
	Short-billed Dowitcher	*Limnodromus griseus*		x	x	x	x		x			
	Long-billed Dowitcher	*Limnodromus scolopaceus*		x		x	x					
	Common Snipe	*Gallinago gallinago*		x	x	x	x					
	Wilson's Phalarope***	*Phalaropus tricolor*			x	x	x		x			
	Red-necked Phalarope	*Phalaropus lobatus*			x	x	x					
	Franklin's Gull	*Leucophaeus*				x	x		x			
	Bonaparte's Gull	*Chroicocephalus philadelphia*	x	x	x	x						
	Ring-billed Gull	*Larus delawarensis*	x	x	x	x						
	California Gull	*Larus californicus*	x	x	x	x	x		x	x		
	Herring Gull	*Larus argentatus*	x	x								
	Caspian Tern***	*Hydroprogne caspia*	x	x	x							
	Common Tern	*Sterna hirundo*	x	x	x							
	Forster's Tern***	*Sterna forsteri*		x	x							
	Black Tern***	*Chlidonias niger*	x	x	x	x	x					
Columbiformes												
	Mourning Dove	*Zenaida macroura*		x	x	x	x		x	x		
	Rock Pigeon*	*Columbia livia*							x	x		MMS Cliff
Cuculiformes												
	Yellow-billed Cuckoo***	*Coccyzus americanus*		x								
Strigiformes												
	Long-eared Owl	*Asio otus*		x	x	x	x		x	x		
	Short-eared	*Asio flammeus*			x	x	x		x	x		
	Great-horned Owl	*Bubo virginianus*		x	x	x	x		x	x		Cliff
	Snowy Owl	*Bubo scandiacus*			x	x	x		x	x		
	Northern Saw-whet Owl	*Aegolius acadicus*		x								
	Burrowing Owl***	*Athene cunicularia*				x	x		x	x		
Caprimulgiformes												
	Common Nighthawk	*Chordeiles minor*	x	x	x	x	x		x	x		Rocky
	Common Poorwill	*Phalaenoptilus*				x	x		x	x		

Apodiformes												
	White-throated Swift	*Aeronautes saxatalis*			x	x	x		x	x		Cliff Cany.
	Black-chinned Hummingbird	*Archilochus alexandri*		x					x	x		
	Calliope hummingbird***	*Stellula calliope*		x								
	Broad-tailed hummingbird	*Selasphorus platycercus*		x								
	Rufous hummingbird	*Selasphorus rufus*		x		x	x		x	x		
Coraciformes												
	Belted Kingfisher	*Megaceryle alcyon*	x	x								
Piciformes												
	Lewis's Woodpecker***	*Melanerpes lewis*		x								
	Red-headed Woodpecker	*Melanerpes erythrocephalus*		x								
	Yellow-bellied Sapsucker	*Sphyrapicus varius*		x								
	Red-naped Sapsucker	*Sphyrapicus nuchalis*		x								
	Downy Woodpecker	*Picoides pubescens*		x								
	Hairy Woodpecker	*Picoides villosus*		x								
	Northern Flicker	*Colaptes auratus*		x								
Passeriformes												
	Olive-sided Flycatcher	*Contopus cooperi*		x								
	Western Wood-pewee	*Contopus sordidulus*		x								
	Cordilleran Flycatcher	*Empidonax occidentalis*		x								
	Willow Flycatcher	*Empidonax traillii*		x								Cany.
	Gray Flycatcher	*Empidonax wrightii*		x						x		
	Hammond's Flycatcher	*Empidonax hammondii*		x						x		
	Dusky Flycatcher	*Empidonax oberholseri*		x						x		
	Least Flycatcher	*Empidonax minimus*		x								
	Say's Phoebe	*Sayornis saya*		x		x	x		x	x		MMS Cany.
	Western Kingbird	*Tyrannus verticalis*		x		x	x		x	x		MMS
	Eastern Kingbird	*Tyrannus tyrannus*		x					x	x		
	Horned Lark	*Eremophila alpestris*				x	x		x	x		
	Northern Shrike	*Lanius excubitor*		x		x	x		x	x		
	Loggerhead Shrike***	*Lanius ludovicianus*		x		x	x		x	x		
	Red-eyed Vireo	*Vireo olivaceus*		x								
	Warbling Vireo	*Vireo gilvus*		x								
	Plumbeous Vireo	*Vireo plumbeus*		x								
	Blue Jay	*Cyanocitta cristata*		x								
	Clark's Nutcracker	*Nucifraga*		x								
	Black-billed Magpie	*Pica hudsonia*		x	x	x	x		x	x		MMS
	American Crow	*Corvus brachyrhynchos*		x	x	x	x		x	x		MMS
	Common Raven	*Corvus corax*		x	x	x	x		x	x		Cliff MMS

	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	x	x	x	x	x		x	x		Cliff MMS
	Bank Swallow	*Riparia ripiria*	x	x	x	x	x		x	x		
	Violet-green Swallow	*Tachycineta thalassina*	x	x						x		
	Tree Swallow	*Tachycineta bicolor*	x	x	x	x	x		x			
	Cliff Swallow	*Petrochelidon pyrrhonota*		x	x	x	x		x	x		Cliff MMS
	Barn Swallow	*Hirundo rustica*			x	x	x		x	x		MMS
	Mountain Chickadee	*Poecile gambeli*		x								
	Black-capped Chickadee	*Poecile atricapillus*		x								
	Red-breasted Nuthatch	*Sitta canadensis*		x						x		
	White-breasted Nuthatch	*Sitta carolinensis*		x						x		
	Brown Creeper	*Certhia americana*		x								
	Rock Wren	*Salpinctes obsoletus*							x	x		Cliff Rocky
	Bewick's Wren	*Thryomanes bewickii*		x						x		
	House Wren	*Troglodytes aedon*		x								
	Marsh Wren	*Cistothorus palustris*			x							
	Rudy-crowned Kinglet	*Regulus calendula*		x								
	Blue-gray Gnatcatcher	*Polioptila caerulea*		x								
	Townsend's Solitaire	*Myadestes townsendi*		x								
	Mountain Bluebird	*Sialia currucoides*				x	x		x	x		
	American Robin	*Turdus migratorius*		x		x	x		x	x		MMS
	Veery	*Catharus fuscescens*		x								
	Swainson's	*Catharus ustulatus*		x								
	Hermit Thrush	*Catharus guttatus*		x						x		
	Gray Catbird	*Dumetella carolinensis*		x						x		
	Northern Mockingbird	*Mimus polyglottos*		x		x	x		x	x		MMS
	Sage Thrasher	*Oreoscoptes montanus*								x		
	Brown Thrasher	*Toxostoma rufum*		x						x		
	European	*Sturnus vulgaris*				x	x		x	x		MMS
	American Pipit	*Anthus rubescens*	x			x	x		x			
	Bohemian Waxwing	*Bombycilla garrulus*		x								
	Cedar Waxwing	*Bombycilla cedrorum*		x						x		
	Tennessee	*Oreothlypis peregrina*		x								
	Nashville Warbler	*Oreothlypis ruficapilla*		x						x		
	Orange-crowned Warbler	*Oreothlypis celata*		x								
	Virginia's Warbler***	*Oreothlypis virginiae*		x								
	Yellow Warbler	*Dendroica petechia*		x						x		
	Chestnut-sided Warbler	*Dendroica pensylvanica*		x						x		
	Magnolia Warbler	*Dendroica magnolia*		x								
	Yellow-rumped Warbler	*Dendroica coronata*		x								

	Pine Warbler	*Dendroica pinus*		x								
	American	*Setophaga ruticilla*		x								
	Northern Waterthrush	*Parkesia noveboracensis*		x	x							
	MacGillivray's Warbler	*Oporornis tolmiei*		x								
	Common Yellowthroat	*Geothlypis trichas*		x	x	x	x		x			
	Wilson's Warbler	*Wilsonia pusilla*		x						x		
	Yellow-breasted Chat	*Icteria virens*		x								
	Western Tanager	*Piranga ludoviciana*		x		x			x	x		
	Rose-breasted Grosbeak	*Pheucticus ludovicianus*		x						x		
	Black-headed Grosbeak	*Pheucticus melanocephalus*		x								Cany.
	Lazuli Bunting	*Passerina amoena*		x						x		
	Indigo Bunting	*Passerina cyanea*		x					x	x		Cany.
	Dickcissel	*Spiza americana*				x			x			
	Green-tailed Towhee	*Pipilo chlorurus*		x						x		
	Spotted Towhee	*Pipilo maculatus*		x						x		
	American Tree Sparrow	*Spizella arborea*		x	x	x	x		x	x		MMS
	Chipping Sparrow	*Spizella passerina*		x		x	x		x	x		
	Brewer's Sparrow***	*Spizella breweri*								x		
	Vesper Sparrow	*Pooecetes*				x	x		x	x		
	Lark Sparrow	*Chondestes grammacus*		x		x	x		x	x		
	Sage Sparrow***	*Amphispiza belli*								x		
	Lark Bunting	*Calamospiza melanocorys*							x	x		
	Savannah Sparrow	*Passerculus sandwichensis*				x	x		x			
	Grasshopper Sparrow	*Ammodramus savannarum*				x	x		x	x		
	Fox Sparrow	*Passerella iliaca*		x								
	Song Sparrow	*Melospiza melodia*		x	x							
	Lincoln's Sparrow	*Melospiza lincolnii*		x								
	Harris's Sparrow	*Zonotrichia querula*		x		x			x	x		
	White-crowned Sparrow	*Zonotrichia leucophrys*		x		x	x		x	x		
	Dark-eyed Junco	*Junco hyemalis*		x					x	x		
	McCown's Longspur***	*Rhynchophanes mccownii*				x	x		x			
	Lapland Longspur	*Calcarius lapponicus*				x	x		x			
	Chestnut-collared Longspur***	*Calcarius ornatus*					x		x			
	Snow Bunting	*Plectrophenax nivalis*	x			x	x		x			
	Western Meadowlark	*Sturnella neglecta*				x	x		x	x		
	Bobolink***	*Dolichonyx oryzivorus*			x	x	x					
	Brown-headed Cowbird	*Molothrus ater*		x	x	x	x		x	x		
	Yellow-headed Blackbird	*Xanthocephalus xantheocephalus*			x	x	x					
	Red-winged Blackbird	*Agelaius phoeniceus*		x	x	x	x					

	Rusty Blackbird	*Euphagus carolinus*		x	x	x			x			
	Brewer's Blackbird	*Euphagus cyanocephalus*		x	x	x	x		x	x		
	Common Grackle	*Quiscalus quiscula*		x	x							
	Bullock's Oriole	*Icterus bullockii*		x								
	Evening Grosbeak	*Coccothraustes vespertinus*		x						x		
	Gray-crowned Rosy- Finch	*Leucosticte tephrocotis*							x	x		
	Black Rosy-Finch***	*Leucosticte atrata*							x	x		
	Pine Grosbeak	*Pinicola enucleator*		x								
	Cassin's Finch	*Carpodacus cassinii*		x								
	House Finch*	*Carpodacus mexicanus*		x					x	x		MMS
	Pine Siskin	*Spinus pinus*		x		x	x		x	x		
	Common Redpoll	*Acanthis flammea*		x					x	x		
	American Goldfinch	*Spinus tristis*		x		x	x		x			
MAMMALS												
Insectivora												
	Vagrant Shrew	*Sorex vagrans*		x								
	Merriam's Shrew	*Sorex merriami*		x		x	x		x	x		
	Northern Water Shrew	*Sorex palustris albibarbis*	x	x								
	Masked Shrew	*Sorex cinereus*		x		x						
	Montane Shrew	*Sorex monticolus*		x		x			x			
Chiroptera												
	Western Small-footed Myotis	*Myotis ciliolabrum*	x	x	x	x	x		x	x		Cliff
	Western Long-eared Myotis***	*Myotis evotis*	x	x	x	x	x		x	x		Cliff MMS
	Townsend's Big-eared Bat***	*Corynorhinus townsendii*				x	x		x	x		NR
	Little Brown Bat	*Myotis lucifugus*	x	x	x	x	x		x	x		Cliff MMS
	Long-legged Myotis	*Myotis volans*	x	x	x	x	x		x	x		Cliff MMS
	Hoary Bat	*Lasiurus cinereus*	x	x	x	x	x		x	x		
	Big Brown Bat	*Eptesicus fuscus*	x	x	x	x	x		x	x		Cliff MMS
	Silver-haired Bat	*Lasionycteris noctivagans*	x	x	x	x	x		x	x		MMS
	Pallid Bat***	*Antrozous pallidus*				x	x		x	x		Cliff

Rodentia												
	Least Chipmunk	*Tamias minimus*		x		x	x		x	x		
	Yellow-bellied Marmot	*Marmota flaviventris*				x	x		x	x		Rocky
	Golden-mantled Ground Squirrel	*Spermophilus lateralis*							x	x		
	Uinta Ground Squirrel	*Spermophilus armatus*							x	x		
	Wyoming Ground Squirrel	*Spermophilus elegans*							x	x		
	Thirteen-lined Ground Squirrel	*Spermophilus tridecemlineatus*							x			
	White-tailed Prairie Dog***	*Cynomys leucurus*								x		
	Northern Pocket Gopher	*Thomomys talpoides*		x		x						
	Olive-backed Pocket Mouse	*Perognathus fasciatus*							x	x		
	Great Basin Pocket Mouse	*Perognathus parvus*					x		x	x		
	Ord's Kangaroo Rat	*Dipodomys ordii*					x		x	x		Sandy
	Beaver	*Castor canadensis*	x	x	x							
	Deer Mouse	*Peromyscus maniculatus*		x		x	x		x	x		
	Northern Grasshopper Mouse	*Onychomys leucogaster*				x	x		x	x		
	Bushy-tailed Woodrat	*Neotoma cinerea*										Rocky
	Montane Vole	*Microtus montanus*		x		x	x		x	x		
	Long-tailed Vole	*Microtus longicaudus*		x		x			x			
	Meadow Vole	*Microtus pennsylvanicus*		x	x	x			x			
	Sagebrush Vole	*Lemmiscus curtatus*							x	x		
	Muskrat	*Ondatra zibethicus*	x	x	x							
	Western Jumping Mouse	*Zapus princeps*		x		x			x			
	Porcupine	*Erethizon dorsatum*		x					x	x		
Lagomorpha												
	White-tailed Jackrabbit	*Lepus townsendii*				x	x		x	x		
	Desert Cottontail	*Sylvilagus audubonii*							x	x		
	Pygmy Rabbit***	*Brachylagus idahoensis*								x		

Carnivora												
	Coyote	*Canis latrans*		x	x	x	x		x	x		
	Red Fox	*Vulpes vulpes*		x	x	x	x		x	x		
	Swift Fox***	*Vulpes velox*							x	x		NR
	Black Bear	*Ursus americanus*		x								
	Short-tailed Weasel or Ermine	*Mustela erminea*		x		x	x		x	x		
	Long-tailed Weasel	*Mustela frenata*		x		x	x		x	x		
	Mink	*Mustela vison*	x	x	x							
	Black-footed Ferret***	*Mustela nigripes*							x	x		NR
	American Badger	*Taxidea taxus*				x	x		x	x		
	Striped Skunk	*Mephitis mephitis*				x	x		x	x		MMS
	Raccoon	*Procyon lotor*		x	x	x						
	River Otter***	*Lutra canadensis*	x	x	x							
	Bobcat	*Lynx rufus*		x					x	x		
Artiodactyla												
	Moose	*Alces americanus*		x	x	x						
	Elk	*Cervus elaphus*		x		x			x	x		
	Mule Deer	*Odocoileus*		x		x	x		x	x		
	Pronghorn	*Antilocapra americana*				x	x		x	x		

* = introduced/non-native

*** = species of concern (from WY Natural Diversity Database and also includes SOC defined by TNC and PIF; does WY "species of potential concern" unless a SOC species by TNC or PIF)

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